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2ND MIAMI INTERNATIONAL CONFERENCE ON ALTERNATIVE ENERGY SOURCES

10-13 December 1979
Miami Beach, Florida

PROCEEDINGS OF CONDENSED PAPERS

Clean Energy Research Institute
School of Engineering and Architecture
University of Miami, Coral Gables, Florida
Edited by
T. Nejat Veziroğlu

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Presented by:

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In cooperation with:

International Association for Hydrogen Energy
International Atomic Energy Agency
International Solar Energy Society
Florida International University
Florida Solar Energy Center
Mechanical Engineering Department,
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ACKNOWLEDGEMENTS

The Conference Committee gratefully acknowledges the support, help and cooperation of the International Association for Hydrogen Energy, International Atomic Energy Agency, International Solar Energy Society, Florida International University, Florida Solar Energy Center, and the Mechanical Engineering Department, University of Miami.

We also wish to extend sincere appreciation to the Invited Lecturer, Robert Tanenhaus, International Energy Agency, to the Keynote Speaker, James E. Funk, University of Kentucky, and to the Banquet Speaker, Mike McCormack, U.S. Representative from Washington.

Special thanks are due to our authors and lecturers who provided the substance of the conference as published in condensed form in the present proceedings.

And last, but not least, our debt of gratitude is owed to the Session Chairmen and Session Co-Chairmen for the organization and execution of the technical sessions.

2nd Miami International Conference
on Alternative Energy Sources
Committee
October 1979

FOREWORD

Fossil fuels, particularly oil and gas, which presently provide most of our energy requirements, are rapidly being depleted. Coal has been less actively utilized since it is less convenient and creates more environmental problems.

Alternative sources of energy are available, but are at present either relatively undeveloped technologically or not utilized fully. Some of these are renewable, such as solar radiation, hydro, wind, ocean thermal and salinity gradient energy. Others are depletable but relatively untapped, such as geothermal heat, or synthetic fuels from coal or wastes. Nuclear energy as presently produced depletes uranium more rapidly than energy from breeder reactors. Nuclear fusion is still a hope for the future. Hydrogen is a suitable synthetic fuel for many applications and has an unlimited raw material base - water. It requires the development of an environmentally acceptable energy source, preferably a non-depleting one, to produce it.

After the successful First Miami International Conference on Alternative Energy Sources, held in December 1977, this conference covers the results of research and developments which have taken place during the last two years. It includes sessions on solar energy, ocean thermal energy, wind energy, hydro power, nuclear breeders and nuclear fusion, synthetic fuels from coal or wastes, hydrogen production and uses, formulation of workable policies on energy use and energy conservation. Most of the sessions are of a technical nature and include selected papers presented by engineers, scientists, economists, planners, managers and educators. However, two sessions will be open to the public, viz., Sessions 5F and 7F, in order to provide a public understanding of the problems associated with alternative energy sources.

The overall objective of the conference is to inform those who attend of the present state of the art and the rate of progress in each of the alternative energy forms. This will include the latest information on the status of alternative energy sources research, development and applications. A rational basis for identification of individual areas of alternative energy sources for further research and identification will be established. Active participation by authors and listeners should provide the direction and stimulation for further research, development and policy formulations.

This volume of Proceedings presents the papers and lectures in condensed format grouped by their subjects under forty technical sessions. It is expected that this document will serve as a concise reference volume covering the latest developments in the field of alternative energy sources.

T. Nejat Veziroğlu
Conference Chairman & Editor

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Coral Gables, Florida 33124, USA

SESSION 1A

SOLAR COLLECTORS I

ANALYSIS OF A HIGH PERFORMANCE TUBULAR SOLAR COLLECTOR

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EXTENDED ABSTRACT

INTRODUCTION

Several solar-powered heating and cooling facility modifications are being planned for the Deep Space Network Tracking Stations at JPL to help reduce the station's energy consumption and operation costs. In order to support the relevant feasibility and advanced engineering studies, special attention is given to new technologies in low-concentration, non-tracking solar collectors. These non-imaging low-concentration types possess, for this particular application, several advantages compared to the high temperature, high concentration ones. Examples are: 1) Their ability to harness diffuse and direct portions of the sunlight, 2) Low cost due to less precision requirements in manufacturing, no sun-tracking mechanism, and no sophisticated optics controls, and 3) Good collection efficiency in the range of heating/cooling interest from 80 to 140^{o}C.

One of the new designs that emerged in this field is the tubular and evacuated solar collector recently manufactured by General Electric. This paper presents the details of the two dimensional, steady state thermal analysis and the results of the computerized simulation, and parameterization made to the collector performance.

COLLECTOR DESCRIPTION

One collector module consists of 8-10 collector units with each unit as shown in Figure 1. Each collector unit consists of two coaxial glass tubes with an evacuated and sealed space between them to form a "thermos-bottle" effect. A thin cylindrical metallic sheet conforms to the inside diameter of the inner glass tube and is attached to a copper U-tube carrying the working fluid. The units are mounted in parallel with a highly reflective back reflector. The U-shaped copper tube is connected in series in the module to form a serpentine.

THERMAL ANALYSIS

The following assumptions were made to simplify the analysis: 1) The collector is assumed at steady state, located in an environment with uniform ambient temperature and solar irradiation. 2) The problem is treated as a two-dimensional heat transfer in the axial and radial directions. Collector tubes are assumed to be of uniform temperature in the tangential direction regardless of the possible non-uniform solar flux distribution on the outer glass tube. In the radial direction, the temperature distribution is assumed to be in steps with negligible conduction thermal resistance for all thin tubes. 3) Axial conduction heat transfer is neglected. 4) Material optical properties are assumed uniform and independent of temperature and direction. Physical properties for solids and liquids are also assumed uniform and independent of working temperature and pressure. 5) Sky and ambient temperatures are assumed approximately the same. 6) The convective heat transfer coefficient between the serpentine tube and either the hot or cold fluid sides is assumed the same since its variation with temperature is insignificant. The convective coefficient is a dominant function of tube diameter, length and fluid mass flow. 7) The outer surface of the second glass tube is assumed to be selectively coated to reduce the outward long-wave radiation losses to the first glass tube. 8) The deformation, due to lateral thermal expansion of the U-shape tube is assumed to be insignificant and not to cause any glass breakage. Also, the present slit suggested by the manufacturer in the metallic shell is assumed to be narrow enough to keep the cold and hot fluid tubes always in contact with the shell. This assumption is made to increase the fin efficiency and improve the heat transfer between the fluid and the copper shell.

With the given or estimated material and physical properties, the collector characteristic equation is found to be approximately expressed as

$$\eta_{module} = 0.640 - 2.0669 \frac{Tc(o) - Ta}{I} \qquad (1)$$

wher $T_c(o)$ is the inlet fluid temperature for the first collector unit in ^oc, T_a is the ambient temperature in ^oc and I is the total solar intensity in W/m^2.

After writing the energy balance and rate equations for a segment of the collector tube, the analytical solution is reduced to the formulation of two simultaneous linear differential equations characterizing the collector thermal behavior. A general solution was obtained, which was found analogous to the general Hottel, Whillier and Bliss form, but with a complex flow factor.

PERFORMANCE SENSITIVITY AND PARAMETERIZATION

A computer program has been written to simulate the collector performance and its sensitivity to the various operating and design parameters. A comparison of the simulated performance with the available manufacturer's test data has shown a good agreement as shown in Fig. 2.

The performance sensitivity has been also provided in the article in order to check on the performance at a wide range of operating conditions and search for the dominant parameters to improve the present design. Nine design and performance parameters were investigated to evaluate the efficiency sensitivity to their changes. The parameters considered are 1) solar radiancy, 2) wind speed, 3) ambient temperature, 4) reflectivity of absorber shell, 5) emissivity of glass tubes, 6) reflectivity of back panels, 7) tubing size, 8) fluid flow rate, and 9) temperature of fluids entering a collector module. The results of the parameterization study are presented graphically and analyzed in detail. The results have shed some light onto variables of insignificant effects and others that need to be modified in order to yield a much higher performance than the present design.

ACKNOWLEDGMENT

This paper presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under Contract NAS7-100, sponsored by the National Aeronautics and Space Administration.

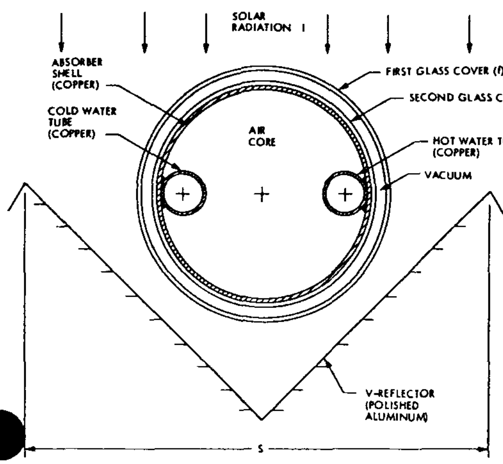

Fig 1 Collector unit

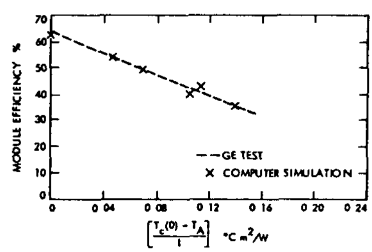

Fig 2. Performance comparison between some simulated and experimental data

A SIMULATED COMPARISON OF THE USEFUL ENERGY GAIN IN FIXED AND TRACKING FLAT PLATE AND EVACUATED TUBE COLLECTORS

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EXTENDED ABSTRACT

A study is presented here of the comparison of the useful energy gain for eight different modes of solar collection. Three of these are fixed flat plate of single cover, double cover and double cover with selective surface, facing due south. Two are full tracking flat plate of double cover and double cover with selective surface. Two are single axis tracking (azimuth angle) flat plate of double cover and double cover with selective surface, and one is an array of evacuated tube collectors facing due south. The study was at Kings Point, N.Y., using actual meteorological and solar data for the entire year of 1977 applied to "theoretical" flat plate and evacuated tube collectors.

This paper is divided into three parts. In the first part of the ratio of hourly beam radiation on a tilted surface to that on a horizontal surface, R_b, is calculated for a fixed and tracking flat plate and for evacuation tube collectors. The ratio of total hourly radiation on a tilted surface to that on a horizontal surface, R, is then found for various collection modes using R_b and a knowledge of the ratio of daily diffuse radiation to daily total radiation on a horizontal surface. A digital computer is then used to calculate the daily useful energy gain for the various collection modes, using the Hottel and Whillier collector equation and hourly values of solar radiation on a tilted surface, ambient temperature and wind velocity. The results show signigicant increases in useful energy gain can be achieved by allowing a flat plate collector to track on either one or two axis.

In the second part of this paper an analysis is made of the collector cost in relation to the useful energy gain for the various collection modes. In this way one can find the collection mode that will yield the highest monthly energy gain per initial dollar invested. The results show that a single axis (aximuthal) tracking flat plate collector and an initial cost of $170 per square meter will yield the highest monthly energy gain per initial dollar invested as compared to the other collection modes tested.

In the third part of this paper various modes of energy collection are tested as part of a solar domestic hot water heating system in order to observe the relative portion of monthly hot water load that can be assumed by each mode. The results show that significant increases in fraction of heating load assumed by the solar system can be achieved by allowing a flat plate collector to track on a single axis.

The results of this study give a detailed analysis of the advantages and disadvantages of various collection modes at a northern latitude.

SOLAR IMAGE CHARACTERISTICS OF CONCENTRATORS

by

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Abstract

This work investigates the concentrators which achieves concentration of Solar Energy by the use of reflecting elements positioned to concentrate the incident beams onto a receiver. These concentrators yield non-uniform intensity distributions. For design purposes it is important to know the variation of this intensity.

A mathematical model is developed to find the characteristics of the solar image for a concentrating collector. The model encounters the effect of the size of the solar disc and determines the intensity distribution of the concentrated beam on the receiver. The computer implimentation of the model is such that the geometry of the reflector and the receiver do not have to be specified by explicit mathematical relations. The reflector and the receiver do not need to be axis-symmetric. Therfore, surface imperfections can be considered. Finite planar elements to represent the system for the reflector and the receiver are represented by nine-nodes. The piecewise ray tracing method is adapted to study the incident and the reflected energy. This includes the shading effects by the absorber and the reflector, and also takes into account the multiple reflection.

The intensity distributions for a conical reflector with its base as a receiver is studied. The effect of misorientation is compared with previous studies to check the accuracy of the model. The intensity distributions for conical reflector with cylindrical absorber and a spherical reflector with conical absorber are calculated for various sizes. The effects of misorientation and the surface irregularities in the reflector due to manufacturing errors on the intensity distribution are presented.

INVESTIGATIONS ON THE PREDICTION OF THERMAL PERFORMANCE OF COMPOUND PARABOLIC CONCENTRATORS

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EXTENDED ABSTRACT

INTRODUCTION

Compound parabolic concentrators (CPC) belong to the particular class of collectors which can achieve the highest possible concentration for a given acceptance angle, and provide higher temperatures than flat-plate collectors, but without the need for sophisticated tracking as required in focussing collectors. [1,2].

The heat transfer processes occuring in the CPC are convective and radiative heat exchange between the absorber and the glazing in the presence of the reflector, which renders the analysis rather complex. Not much work appears to have been done on the prediction of thermal performance of CPC collectors.

PREDICTION OF THERMAL PERFORMANCE OF CPC

The present work proposes an iterative scheme to predict the temperatures of the absorber, the glazing, and the outlet fluid, and for the evaluation of convective and radiative losses and the collector efficiency, for given values of mass flow rate and insolation, under steady-state conditions. The computations are performed for different concentration ratios for a single glazed CPC collector.

The analysis presented in Ref. [2] for the evaluation of convective and radiative losses forms the basis for the present investigation. That analysis is based on the prediction of glazing temperature for an *assumed* absorber temperature, whereas the present scheme is more general.

ANALYSIS AND RESULTS

The following steps are involved in the iterative scheme:

(a) For an assumed absorbed temperature (T_s) the outlet fluid temperature (T_2) is predicted using the appropriate heat transfer relationship [3]. If the rate of energy by the fluid is not balanced by the rate of heat transfer from the absorber, the fluid outlet temperature is changed until convergence is accomplished.

(b) The glazing temperature is predicted for the assumed T_s and ambient conditions by solving alternatively the energy balance for the collector, from which the losses can be computed. This procedure yields another value of useful heat gained by the fluid, which would be the same as the heat transfer rate computed earlier in (a), if the assumed T_s were correct. Otherwise, the value of T_s is changed and the procedure is repeated again until satisfactory convergence is achieved. On the average, about fifteen iterations are required for predicting the absorber temperature, T_s, for a given insolation and mass flow rate.

The analysis yields the following results:

1. The absorber and outlet fluid temperatures follow the insolation curve through most of the day. The difference between the absorber and the outlet temperatures is maximum at noon.
2. Collector efficiency increases with flow rate, for the concentration ratios investigated (1.6, 5.0 and 8.0).
3. In the range of parameters investigated, a concentration ratio of five is found to be optimal from the standpoint of collector performance.
4. Wind velocities from 4.5 to 15.0m/s have negligible influence on the collector performance for a concentration ratio of five.

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SESSION 1B

PHOTOVOLTAICS I

THE DOE PHOTOVOLTAICS PROGRAM - AN OVERVIEW*

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ABSTRACT

The United States Department of Energy National Photovoltaics Program objective is to bring photovoltaic power systems to a point where they can supply a significant portion of the United States energy requirements by the year 2000. This will be accomplished through substantial research, development, and demonstration aimed at achieving major cost reductions and market penetration.

A program overview is presented covering the Photovoltaics Multi-Year Program Plan, array and system price goals, program organization, major milestones and resources. The present status of photovoltaics technology development is discussed, including existing and planned installations. Near future application projections include the Federal Photovoltaics Utilization Program, and potential international applications.

*The work described in this paper was carried out or coordinated by the Jet Propulsion Laboratory, California Institute of Technology, and was sponsored by the U.S. Department of Energy through an agreement with the National Aeronautics and Space Administration.

TECHNOLOGY ASSESSMENT OF DISTRIBUTED PHOTOVOLTAICS

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EXTENDED ABSTRACT

The terms 'Technology Assessment' and 'Distributed Photovoltaics' are defined as used in the current study. The main emphasis shall be placed on the determination of feasibility of distributed photovoltaics to become "cost competitive with utility generated electricity from conventional sources' [1]. A look is taken at the programs of the U.S. Department of Energy towards meeting this goal. With the assumption that these cost goals are actually achievable, economic comparison between distributed photovoltaics and central station generating plant with conventional resources is made. The time frame for the comparison is late 1980's. Attention is given to the break-even period for a distributed photovoltaic system with conventional energy supplier.

Comparison is made between the load profiles of a utility company over a day and year with daily and annual solar insolation variations. It is shown that the variations follow almost identical curves, making it very feasible, theoretically, for a utility company to cut the peak off the maximum demand of summer noons. Of course, minor variations due to geographical locations are not considered.

An attempt has been made to determine the applicability of economy of scale to the photovoltaic conversion process. It is revealed that in spite of the pervasive belief in the gigantism of conventional power plants, increases in scall does not necessarily yield lower cost per unit of output, in case of photovoltaic conversion.

Contrary to the photovoltaics 'system' as electricity producing plant, the photovoltaic cell/array manufacturing process itself, like many other manufacturing sectors, follows the economy of scale. It is briefly described how, with the wide range applications of the photovoltaic system, the cost of cells (and the system) will go down substantially. Attention is brought to several market penetration scenarios drawn by different groups and their effects on the photovoltaic array prices. From the closeness between semiconductor devices and the solar arrays, conclusion is arrived at. It is examined whether the Department of Energy cost goals are supported by the penetrable market.

Institutional barriers to large scale terrestrial applications of distributed (or central station) photovoltaics are enumerated. It is predicted that even after the technological and economic barriers are overcome, the distributed photovoltaics system will take a much longer period to find wide range social acceptance.

1. Solar Photovoltaic Energy Research, Development and Demonstration Act of 1978, Public Law 95-590.

APPLICATION OF A GaAs PHOTOVOLTAIC SOLAR SYSTEM IN A UTILITY SUBSTATION

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EXTENDED ABSTRACT

The solar power system is planned to be installed on property owned by Pacific Gas and Electric Company (PG&E) adjacent to its San Ramon, California, power substation. The substation is surrounded by a rapidly growing middle and upper income residential community which is supplied by distribution lines emanating from the substation. The power output from the photovoltaic installation will be converted to alternating current at a frequency and voltage compatible with the PG&E 21kV distribution line.

The experimental site lies in a shallow valley 25km inland and to the east of the San Francisco Bay area. The site, on the east side of the substation, is part of a large field in an existing transmission-line right-of-way.

A significant portion of the residential electrical consumption in the summer in this area is due to air conditioning loads. An alternative energy source, such as the proposed solar system which peaks in the summer months and during midday, has the potential of considerable generating capacity and of an exceptionally high energetic value to PG&E of 3.4¢/kWh.

This base-line system is typical of a large number of applications for dispersed types of generation which can supply power directly to distribution customers at a time when their demand is highest.

SYSTEM CONSIDERATIONS

The 50kWp system consists of an array field of 14 identical arrays, each delivering 3.8kWp DC power. Each array is self-supporting, i.e., with independent tracking and heat rejection subsystems. Therefore, each array can operate independently from adjacent arrays or the total field. Only electrical inter-array wiring (main bus bar, AC power, tracking) connect the array from the control room where power conditioning from a nominal 540 VDC at 100 amperes to 3∅, 60Hz 480 VAC is performed. In a subsequent operation, a step-up transformer brings the voltage to 21 kV, the line distribution voltage.

The system block diagram is illustrated in Fig. 1. The system is capable of unattended operation under the environmental conditions encountered at the site. The array will assume a stowed position at high wind velocities. Power from the system is injected into a commercial utility distribution system, whenever available. The annual AC electrical energetic output is expected to be around 100,000 kWh.

The collector subsystem consists of hexagonal plastic Fresnel lenses designed to maximize array area utilization. Each array has 440 individual solar cell housings mouted in a honeycomb arrangement covering an area of about 295 ft^2. Utility channels and manifolds contain the electrical wiring and coolant piping. Water-cooled solar cells are protected from the environment by a plastic houseing (cone). The thermal energy produced by the array is evacuated by allowing heat to be rejected to the environment.

The solar cells placed in 44 parallel modules of 10 cells each are mounted on an efficient tracking system with high pointing accuracy. The structural subassembly consists of a tubular H-Frame (supporting all modules) connected to a Y-Frame which also supports the elevation drive. The complete structure is then bolted to a reinforced concrete foundation. The tracking system has a calculated free play of less than 0.1° and a static deflection due to 30 MPH winds of less than 0.2°. Tracking power requirements are less than 12 watts/array.

The power conditioning subsystem (provided by PG&E) consists mainly of a maximum power tracking inverter designed to operate at a variable input voltage of 100-650 VDC.

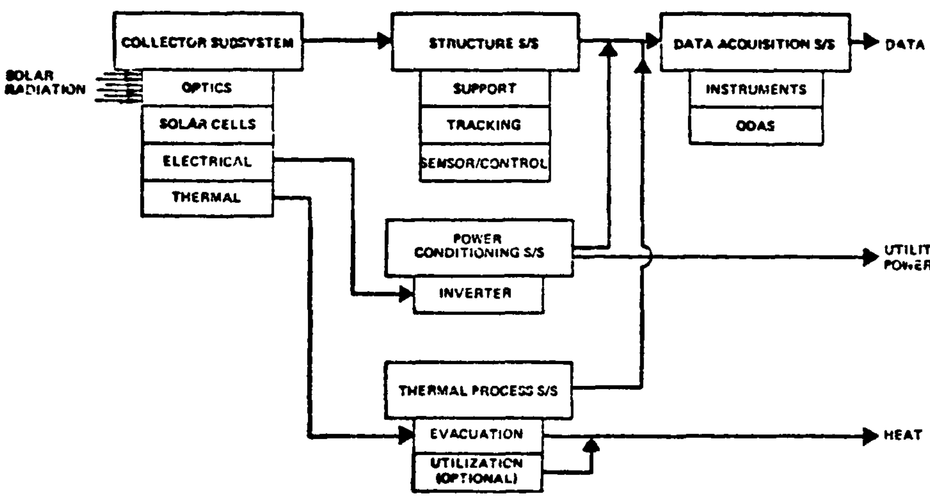

Fig. 1 - System Block Diagram

PROSPECTS FOR DEVELOPING AN EFFICIENT PHOTOEMISSIVE SOLAR CELL

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EXTENDED ABSTRACT

So much attention has been focused on the photovoltaic solar cell (PVC) as a means for obtaining direct electrical conversion of solar energy, that its forerunner, the photoemissive solar cell (PEC), receives no development at all and has all but disappeared from the literature. Certainly, when an early form of operating PEC, having an AgOCs collector and a Na_2KSb emitter, is reported as having a conversion efficiency of only 2% [1], while modern PVCs are commonly produced with efficiencies between 10% and 20% [2], the reason for a lack of interest in the PEC seems legitimate.

Poor efficiencies of early PECs notwithstanding, there now appears to be several good incentives for its renewed study. Recent research into the development of highly efficient photoemissive materials [3,4] indicates that the PEC could, in fact, become efficiency competitive with the PVC. The so-called "negative affinity" photoemitters [4] are an exciting class of appropriate PEC materials whose development seriously lags behind the corresponding development of materials used in PVCs. Finally, the PEC is quite similar in theory and design to certain thermionic converters and, as a consequence, shares many of its problems. The thermionic converter has recently received much favorable consideration as a means of converting waste heat to electricity, so renewed study of the PEC could provide a useful cross-fertilization of that entire technology as well [5,6]

In an effort to undertake a study of possible structures and materials for a more efficient photoemissive cell and, hopefully, to produce an operating prototype cell, we have begun by deriving a simple formula for the efficiency of such a cell in a matched load configuration. This formula indicates the important parameters in optimizing PEC operation and also reflects some of the reasons why its efficiency is so low.

$$\epsilon = (\phi_e - \phi_c)\, e\bar{\eta}\bar{R}\,(h\bar{\nu})^{-1}$$

In the preceding expression, ϕ_e and ϕ_c are, respectively, the emitter and collector work functions, h is Planck's

constant, e is the electron charge, $\bar{\nu}$ is the average solar spectrum frequency, $\bar{\eta}$ is the average photoelectric yield (number of electrons emitted per absorbed photon averaged over the incident solar spectrum) and $\bar{\alpha}$ is the number of absorbed photons per number of incident photons averaged over the incident solar spectrum. This formula, which is an approximation, confirms the low efficiencies of earlier PECs, but also implies that new negative affinity emissive materials such as the $GaAs_{1-x} P_x$ alloys [4] would lead to efficiencies up to 30%.

The problems of the PEC cannot be glossed over at this point. The PVC makes efficient use of the solar spectrum because it is only necessary that electrons be excited over the band gap in order for the built in junction fields to sweep them through the junction. In the PEC, however, electrons must not only be excited over the band gap, but they must diffuse to the emitter surface and still retain enough energy to overcome the surface affinity and cross a narrow vacuum region which might contain blocking space charges. Of all these difficulties, the most serious one until now has been the necessity of the electrons overcoming the surface affinity of the emitting surface. This difficulty disappears in the case of negative affinity photoemitters since the electrons, once photoexcited in the bulk, see no surface barrier when they reach the surface. In brief, a negative affinity emissive surface facing a vacuum has similar properties to the grown in p-n junction of a standard PVC. While the negative affinity materials at present suffer from instability problems, they offer great hope that the PEC can, in principle at least, challenge the PVC as a means of direct solar conversion.

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THE EFFECTS OF JUNCTION DEPTH AND IMPURITY CONCENTRATION ON DIFFUSED JUNCTION SOLAR CELLS

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EXTENDED ABSTRACT

INTRODUCTION

Even a cursory survey of the current literature [I] reveals that a plethora of solar cell types exists. Materials range from simple semiconductors such as silicon, GaAs, CdS, CdTe to complex organics and ionic fluids. Contact metals range from aluminum through transparent materials such as indium oxide to complex multiple metal electrodes. Junctions can be metal - semiconductor (Schottky Barrier), ion implanted, heterojunction, diffused, solid-liquid etc. Configurations are horizontal, inverted (the "Purdue" cell) and vertical. Additionally the substrate can be graded, stepped or simple uniform and the surface can have an anti-reflection coating, be textured or have a combination of treatments.

However, the bulk of solar cells in current commercial use, either on earth, or in space are diffused horizontal junction cells made from silicon. In future the market for such cells, or any type for that matter, is likely to be primarily terrestial in origin.

Therefore in this paper we have elected to address certain optimization problems for horizontal homojunction silicon solar cells. The cells are of p+ on n and n+ on p construction and the + region is of a diffused type. The substrate is lightly doped (1×10^{15}) and of constant impurity concentration. The diffused region is of varying depth (.2 to 1μm) and with average impurity concentration from 10^{17} to 10^{20} /m^3. Experimental results are compared to theoretical predictions using a simple model derived elsewhere [II] and summerized below.

THEORETICAL MODEL DISCUSSION

The maximum theoretical efficiency, η, of an ideal diffused junction solar cell in a circuit with a resistive load is given by [II]:

(1) $$\eta(\%) = \frac{(J_{ph} + J_s)\ (\lambda V_D')\ (V_D')}{I_{ns}\ (\lambda V_D' + 1 + K')} \left(1 - \frac{K'/2}{1 + K'}\right) \times 100,$$

where J_{ph} is the induced photo current;
J_s is the saturation current density;
I_{ns} is the solar insolation;
λ is the electronic charge, q, divided by the product of the absolute temperature, T, and Boltzman's Constant, k;
V_D is the junction voltage for maximum power transfer to the load, determined experimentally by varing the load value; and K^1 is the loss factor.

The loss factor is given by:

$$K' = 2r_D\ (J_s\ A)\ \lambda\ \exp\ (\lambda V_D'),$$

(2) Where: r_D is the series resistance of the diode and is composed of a component due to the substrate, constant for these experiments, and a spreading component due to the diffused layer, which depends on the thickness and effective doping of the diffused region as well as the configuration of the contacts; and A is the junction area of the solar cell.

The optimum junction voltage, V_D', and the loss factor are determined theoretically by simulaneous solution of equations (2) and (3):

$$(\lambda V_D + 1 + K)\ \exp \lambda V_D = \frac{J_{ph} + J_s}{J_s}\ (1 + K). \qquad (3)$$

EXPERIMENTAL PROCEDURES

N and P type silicon wafers of 5 x $10^{16}/cm^3$ impurity concentration were lapped on both sides and chemically polished on one side to a thickness of 175μm. A 6μm diffusion of type identical to the substrate was performed on the lapped side prior to the chemical polish. Then these wafers were diffused on the polished side according to varying depths.

Measurement of the device performance and solar insolation were made at the same time, with the sun on device normal, at times ranging from noon to 2:00 p.m. in Flagataff, Arizona, during the months of September and October 1978, and April and June 1979. The solar cell load was a variable resistance whose value was set to provide maximum power transfer.

RESULTS AND DISCUSSION

Figure I presents both theoretical and experimental solar cell efficiency versus junction depth for solar cells with an average diffused region concentration of 5 x $10^{18}/cm^3$ for both p and n type substrates with an insolation of 100 mw/cm^2 (June 1979). Note that performance peaks at junction depths near 0.5μm. For junction depths greater than this value series resistance effects act to decrease the efficiency while for values smaller than 0.5μm lifetime effects at the surface of the solar cells reduce the efficiency. Lifetime effects also are responsible for the slightly higher effectiveness of the n - type substrate devices, at least in theory! A similar efficiency junction depth curve exists for average concentrations of the diffused region of 1 x 10^{17} and 1 x 10^{20} cm^{-3}. The significant variability in individual device performance, as indicated by the bars shows us that we have much to learn about device processing before perfection is achieved.

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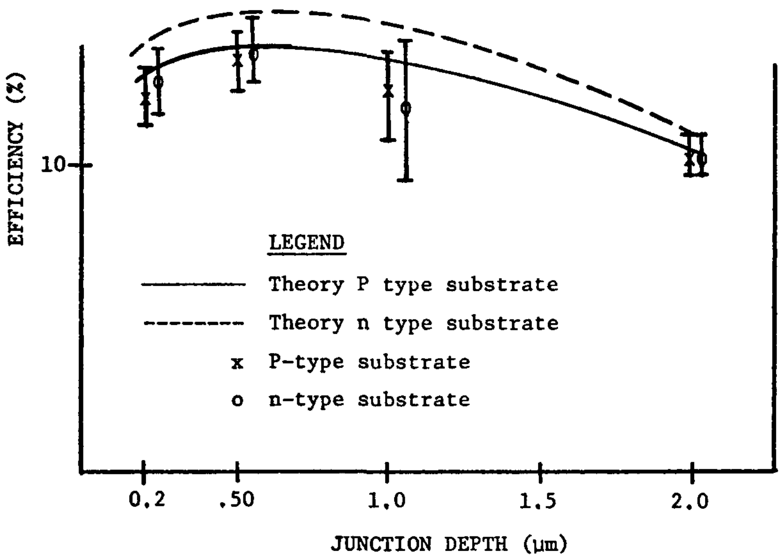

Fig. 1 - Solar Cell Efficiency vs Junction Depth for June (Insolation 100 mw/cm^2). These cells have an average diffusion region concentration of 5 x $10^{18}/cm^3$.

SESSION 1C

NUCLEAR ENERGY I

DOUBLET III EXPERIMENTAL RESULTS AND FUTURE PLANS*

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EXTENDED ABSTRACT

It is now generally acknowledged that operation with a noncircular plasma cross-section will be a necessary feature of a tokamak fusion power reactor. The feasibility of shaping plasmas into vertically elongated configurations and the effects of this shaping on plasma stability and confinement have been investigated at General Atomic Company in a series of noncircular tokamak experiments beginning in 1968. Doublet III is the third and most ambitious of this series, and is specifically designed to study the effects of noncircularity in high-beta, auxiliary-heated plasmas, ultimately with reactor-like parameters.

Ohmic heating experiments in Doublet III began in September 1978. In the period through July 1979, the primary emphasis has been on shaping the plasma to obtain a steady-state noncircular discharge, and on making preliminary measurements of the plasma characteristics. A summary of these studies are presented in this paper.

Doublet III (Fig. 1) is presently the world's largest operational tokamak. The vacuum vessel is nearly 3 meters in height with a mean radius of 1.43 meters and a maximum width of 0.9 m. The maximum toroidal field strength is 26 kG at the center of the vessel. The maximum plasma current achieved to date with a doublet configuration (Fig. 2) is 2.2 MA, more than four times the previous tokamak record. At a typical operating current of 1.5 MA, typical doublet plasma parameters are a central electron temperature of 1 keV, an average plasma density of 4×10^{13} cm^{-3}, and an energy confinement time of about 40 milliseconds. These results are similar to those obtained in circular tokamaks, and indicate

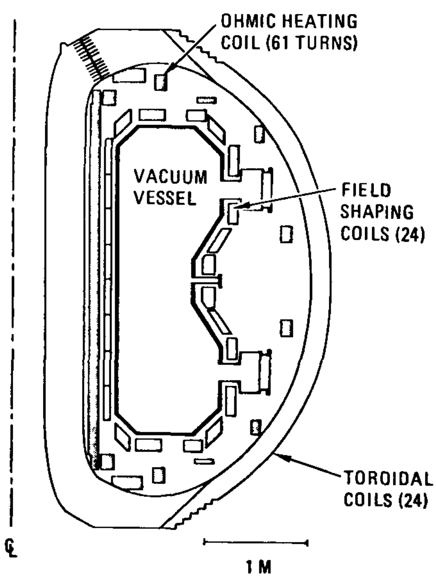

Fig. 1. Cross-section of Doublet III

that the plasma shaping techniques developed in small-scale experiments can be successfully extended to much larger systems. Another significant advance has been extension of the discharge duration to nearly 0.5 second, demonstrating that a doublet plasma can be maintained for the time scale required for future fusion reactor applications.

Future Doublet III plans call for the addition of 7 MW to 80 kV hydrogen neutral beam heating, to raise the plasma temperature to the range required for energy breakeven (> 5 keV). A key aspect of these forthcoming studies will be to study the magnetohydrodynamic stability properties of doublets and experimentally verify that a doublet reactor will be able to operate at a beta value high enough to make a tokamak fusion reactor practical.

*Research supported by Department of Energy Contract DE-AT03-76ET51011.

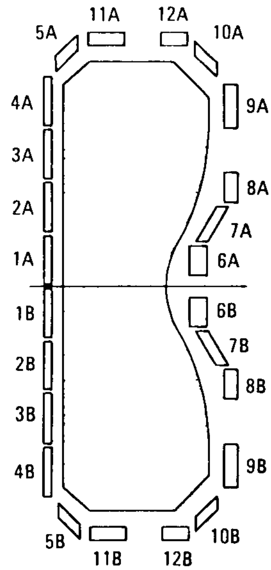

Fig. 2. Doublet plasma configuration

FUSION REACTORS AS HIGH-TEMPERATURE PROCESS HEAT SOURCES

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EXTENDED ABSTRACT

The primary goal of most U S fusion research and development is commercial electric power production. However, ~ 3/4 of total U S energy consumption is for space heating, industrial process heat, and transportation. Electric power can't or won't be used to meet many of these nonelectrical energy requirements for reasons of cost, efficiency, or insurmountable technological barriers. Therefore, if fusion is to be a primary energy source when fossil fuel supplies are exhausted, fusion reactors must be adapted to meet nonelectrical energy requirements, especially for process heat and transportable fuels, or else significant changes in energy consumption patterns must occur.

In our studies of DT fueled fusion process heat sources we have adopted, subject to continuing review as to suitability, the following ground rules. Export of large fractions of plant output as electric power is undesirable because of potential for exaggeration of mismatches between nonelectrical energy supply and demand, although some cogeneration is not ruled out. Although offering potential efficiency and capital cost advantages, direct nuclear heating of process streams is infrequently considered because of neutron-induced radioactivity contamination which is difficult to eliminate from product streams. Most tritium handling and containment problems must be faced whether or not tritium is bred because of incomplete burnup of fuel, routine shipment of large quantities of tritium from one site to another to permit support of nonbreeding reactor by plants with excess tritium breeding capacity may be deemed excessively hazardous and banned by regulatory bodies, and contrary to the thinking in some quarters, tritium will probably not be essentially free in a fusion economy, but will probably sell at or above substantial marginal production costs. Therefore, the major product of our process heat fusion reactor concepts must be high-temperature thermal energy, direct nuclear heating is ruled out, and they must be substantially tritium self-sufficient.

We have concentrated our attention on reactor concepts which deliver heat at ~1500K because of the following considerations:

- Such temperatures permit achievement of higher efficiencies in conversion of primary fusion energy into stored chemical energy of synthetic fuels by existing processes, e.g., by thermochemical cycles or high-temperature electrolysis, because of both higher maximum temperatures and better matching of reactor energy delivery characteristics to process requirements.

- Higher temperature thermal energy delivery allows consideration of new, higher-efficiency industrial processes, including synthetic fuel production, existing fusion reactor concepts can supply heat at lower temperatures, and many large scale, base-load applications, for which fusion reactors appear to be best suited, e.g., steel-making and synthetic fuel production, require such temperatures.

Important characteristics of fusion reactors as process heat sources can be summarized as follows. At least the first few generations of fusion reactors will burn deuterium and tritium, $D+T \rightarrow {}^4He + n +$ energy, because the conditions required to induce useful thermonuclear energy release are less severe than for other fusion reactions. The high-energy reaction ${}^7Li\ (n,n'\alpha)\ T$ plus the low-energy reaction ${}^6Li\ (n,\alpha)\ T$ permit tritium breeding ratios, tritium atoms produced per fusion-born neutron, greater than one, to be achieved with further enhancement of tritium breeding ratio if materials such as lead or beryllium, which multiply neutrons through (n,2n) reactions, are included in fusion reactor blankets. Because tritium is a moderately hazardous radioactive isotope that becomes highly mobile at elevated temperatures, the strict containment and efficient recovery necessary for protection of the public, plant personnel, and the environment at the low blanket concentrations considered necessary for tritium hazards minimization represent substantial design problems. Highly-penetrating 14-MeV fusion neutrons, whose kinetic energies and exoergic reactions with blanket and structural materials represent the majority of fusion reactor energy release, pass through thin solid walls with little energy loss and can be utilized in blankets relatively inependently of reactor cavity phenomenolgy which is generally unfavorable to efficient high-temperature energy utilization. This is an important advantage relative to fission reactors in which the majority of the energy release appears as kinetic energy of fission fragments which have very short ranges in condensed matter. The remainder of fusion energy release, in the form of x-radiation and energetic charged particles, is effectively trapped within reactor cavities. Although this energy can also be recovered at high temperature with some difficulty, conversion of a substantial fraction of total reactor thermal power to electric power is required to supply recirculating power to drive the fusion reactions. Therefore, the recovery of x-ray and plasma energy as high-temperature heat must be justified primarily on the basis of improved electric power cycle conversion efficiency.

A survey of existing fusion reactor blanket concepts developed here and abroad, including Russia, resulted in the conclusion that none of them has the capability for simultaneously delivering a majority of fusion reactor energy release as heat at $\gtrsim$1500K and breeding tritium at a ratio ≥ 1. As part of a study of fusion driven-thermochemical hydrogen production, we have developed tritium-breeding blanket and thermal energy delivery concepts which have this capability and show promise of being effective. One concept, the lithium boiler,[1] involves deposition of neutron energy in lithium or lead-lithium mixtures boiling at 1500-2000K, thermal energy transport by vapor to the primary heat exchanger, and self-pumping if gravity return of condensate is used. This concept has a number of advantages, especially for inertial confinement fusion, including:

- low operating pressures, i.e., only a few atmospheres at most, mechanical simplicity, and temperature uniformity within the blanket,
- thermal energy delivery as latent heat,
- damping of shock waves resulting from nonuniform pulsed neutron energy deposition characteristic of inertial confinement fusion by vapor bubbles, and
- requirement of only modest amount of exotic materials with no resource limitations.

An attempt was also made to adapt this blanket concept for use with magnetic confinement fusion reactor concepts, specifically a tandem mirror reactor design. Ground rules for the adaptation included no increase in solenoidal magnet bore and no decrease in the reference design's $\sim$ 2MW/m^2 neutron wall loading. Reduced blanket neutron stopping power caused by vapor volumes of $\geq$50 v/o at the top of the blanket indicated by available, but suspect, models of the boiling apparently makes adequate shielding of superconducting magnets difficult under these ground rules. Furthermore, the effects of strong magnetic fields on boiling and circulation of internally heated liquid metals are poorly understood. Consequently to avoid these uncertainties, a lithium blanket with boiling suppressed by pressurization was designed to operate at 1500-2000K with lithium circulation by electromagnetic pumps.

Neutronics studies indicate delivery of almost 60% of total fusion reactor energy release as high-temperature heat and tritium breeding ratios of about 1.5 for both concepts. Solutions to the severe materials compatibility and structural design problems associated with lithium containment and heat transfer at such temperatures have been found. Variations, including electric power generation versions of these general schemes, are being explored and capital costs are being assessed.

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Engineering Test Facility (ETF), A New Phase in Fusion Energy Development

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ABSTRACT

The Engineering Test Facility (ETF) will be the focus of the engineering testing phase in the Department of Energy's (DOE) strategy to develop fusion energy as an economically attractive and environmentally acceptable energy option. The ETF Design Center was established by the Office of Fusion Energy in December of 1978. Its objectives are to prepare the ETF conceptual design and to perform the associated project engineering and planning functions in sufficient detail to support a DOE decision in 1984 for the ETF project. This paper presents a summary of the role and the strategy of the ETF based on magnetic confinement, together with a brief account of the objectives, the approach, the work plans and the recent progress of ETF Design Center activities.

Role of ETF

It is anticipated that scientific feasibility of magnetic fusion will be proven in the early 1980's, after which ETF is to provide a testbed for fusion reactor components in the subsequent engineering test phase. The ETF will test subsystems including (1) a clean, long pulse, high β and burning plasma, (2) blanket and shield, (3) superconducting magnets, (4) tritium handling components, and (5) reactor system integration. The engineering and technology data base essential to the subsequent phase of fusion reactor demonstration will be developed. The ETF project work will also provide a yardstick against which the current magnetic fusion program can be measured.

Alternate Confinement Concept Strategy for ETF

Current DOE strategy proposes selection of an ETF fusion core among the competing confinement alternatives in 1984. Based on the scientific evidence at hand, the tokamak concept appears to be the choice that will most ensure the success of the engineering test function and perhaps a prototype fusion reactor. However, alternatives to tokamak, such as mirror and Elmo Bumpy Torus, will be aggressively pursued to challenge this judgement. To maximize the chance of success of the ETF project, the most desirable strategy seems to be: 1) to examine the tokamak design concept to improve any serious drawbacks, 2) to incorporate in the ETF design the engineering tests required by alternate concept reactors, and 3) to prepare ETF designs based on the alternate concepts at reduced and appropriate levels.

Approach

The ETF Design Center activities will have a national scope and involve representation by the principle tokamak centers (i.e., General Atomic, Massachusetts Insitute of Technology, Oak Ridge National Laboratory and Princeton Plasma Physics Laboratory). The alternate concepts being pursued at Los Alamos Scientific Laboratory and Lawrence Livermore Laboratory will also be integrated into the design center deliberations. Industry is expected to play a significant role in the design center activities.

The initial focus of the design center will be on the tokamak concept; as other promising magnetic confinement concepts evolve, they will also be evaluated in the context of the ETF. It should be emphasized that many of the technology problems of magnetic confinement fusion are generic in character so that a tokamak oriented study will be of general value to other magnetic fusion concepts.

Work Plans

The ETF Design Center activities are organized in five areas: plasma system, nuclear systems, electrical systems, magnetic systems, and systems engineering. Six general tasks are involved: 1) design evolution, 2) subsystem development, 3) research and development (R&D) assessment and evaluation, 4) mission statement, 5) interface with other programs, and 6) program and project planning.

Recent Progress

The emphasis of the design center activities during 1979 may be characterized as project definition via the examination and evolution of the ETF mission. Based on a reference ETF mission and in collaboration with the International Tokamak Reactor (INTOR) R&D assessment activities, the ETF design team will form its independent conclusions of R&D needs assessment and evaluations. A baseline design of ETF, as a point of departure, will also be established around the end of 1979.

Conditions of Success

Finally, a number of conditions are necessary before the ETF project can become a reality. These include; 1) the fusion community must be convinced of the technical and political viability of the ETF, 2) the fusion research centers and the industry must support the design center both institutionally and through the assignment of key personnel, 3) the design center activities must be technically sound and reflect community-wide input, 4) the Office of Fusion Energy must support the design center financially and through program direction, and 5) the technical, political and public sectors must be informed and accept the fusion program strategy.

THE LITHIUM QUESTION FOR NUCLEAR FUSION

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EXTENDED ABSTRACT

An attempt is made to estimate the lithium reserve (the economically recoverable lithium resources) and the anticipated requirement for tritium breeding of D-T fusion reactors, lithium batteries, and other uses.

The world lithium reserve has been estimated by many authors and organizations. The results are varying widely. It is our opinion that M. K. Hubbert [1] has cited a more reliable figure of 10^{12} grams as the present lithium reserve contained in the earth crests and natural brines. The world lithium consumption is about 10^{10} grams per year. Two factors must be brought into consideration before we can draw any conclusions from these figures. The first is that, like any other primary goods, the available quantities will undoubtedly increase with higher price,advanced technology, and more favorable incentives. For example, we have examined the lithium quantity contained in the oceans. With some optimistic extrapolation we are able to arrive at a figure of 10^{14} grams of lithium available in the near future. The second influencing factor is the use of lithium for fusion reactors and for lithium batteries [2]. The fusion reactor lithium requirement, at least in the early stages of the fusion power reactor operations, is estimated to be about 10^{11} per year. The lithium battery development is still in its infancy. Potential applications of these batteries are for future electric cars and power plant electric power storage. An oder of magnitude estimate of these requirements is about 10^{12} grams per year. hen all of these factors are considered, it is clear that the most optimistic estimate of the length of time through which lithium supply is adequate is approximately 100 years.

From the above analysis, it is our contention that there is at least a bona fide question of the abundance of our lithium supply. The development of extraction techniques and the exploration of new lithium resources require long lead time. Therefore we must earnestly pursue the following tasks in order to have plentiful of lithium on hand in time to welcome the arrival of the fusion power and electric car age:

1) The lithium resources from the earth crest and in the oceans must be deligently explored.
2) New and advanced technologies must be developed to economically obtain lithium (and other minerals) from the oceans.

It is difficult to expect the private sector to have the incentive and the courage to spend a large sum in the above-mentioned activities. The responsibilities are therfore resting squarely with our governmental

agencies.

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SESSION 1D

GEOTHERMAL ENERGY I

GEOTHERMAL DRILLING RESEARCH IN THE UNITED STATES*

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EXTENDED ABSTRACT

The cost of drilling and completing geothermal wells in the United States is presently two to four times that of conventional oil and gas wells of the same depth. The high cost of these wells is an impediment to the timely development of geothermal energy. Sandia Laboratories manages a research and development program for the Department of Energy that is aimed at reducing the cost of drilling and completing geothermal wells. This paper presents an overview of this research and development program and provides technical details about each program area.

DRILLING HARDWARE

The development of improved rotary drilling hardware is necessary to reduce the cost of drilling and completing geothermal wells. Included in this activity are the development of improved geothermal roller cone bits, the development of polycrystalline diamond compact drag bits and the development of the continuous chain drill. In the roller bit development program, Terra Tek, Inc., is investigating the use of improved materials in unsealed roller bits and is also performing testing and evaluation of improved high temperature seals and lubricants for sealed roller cone bits. Experimental bits have been fabricated using materials with higher hot hardness in critical wear areas. These bits have been tested in geothermal drilling at The Geysers. Significant improvements in performance were achieved over that obtainable with conventional bits, and a cost savings of approximately 4% of total well cost is projected when these bits are used exclusively. Research directed at improving sealed roller cone bits has lead to the formulation of several new elastomeric compounds, as well as to the identification of promising high temperature lubricants. Work on polycrystalline diamond compact bits has recently lead to field testing of new bit designs that have increased penetration rates by factors of two to three depending on the formation encountered. The continuous chain drill, which is a system that allows the replacement of the cutting surface of the bit without removing the bit from the hole, has recently been field tested by Sandia Laboratories. In the present design, approximately

*This work is supported by the U. S. Department of Energy.

fifteen bit changes can be achieved before tripping the bit out of the hole. Based on these successful field tests, further development will be carried out in conjunction with private industry.

DRILLING FLUIDS

Non-corrosive high temperature drilling fluids are required in all areas of geothermal drilling. In some reservoirs, drilling mud can be used, and research is presently emphasizing the determination of the rheological properties of drilling fluids under conditions of high temperature and high pressure. Test facilities for conducting these measurements under simulated downhole conditions have been constructed. Additional research is being carried out to determine the morphology which occurs in clays as a function of temperature.

Light-weight drilling fluids are of significant importance in geothermal drilling. Present developmental activities involve the design, fabrication, and testing of portable systems capable of generating nitrogen in quantities of 1200 SCFM at 400 psi. This will reduce corrosion rates by reducing the amount of oxygen present in the fluid. Designs for portable nitrogen generation systems involving both cryogenic separation and the conversion of diesel exhaust gas into nitrogen are under study. In addition, the development of high temperature drilling foams has the potential for significant cost reductions. Presently, screening tests of existing surfactants are underway to determine their temperature stability and foam generation capabilities.

LOST CIRCULATION CONTROL

Geothermal reservoirs are typically found in highly fractured formations. In these formations, lost circulation presents a significant problem in terms of drilling costs and in the completion of the well after drilling. Currently, new high temperature materials for sealing lost circulation zones are needed. In addition, completion techniques which will allow completion of the well through these highly fractured formations are under study.

COMPLETION TECHNOLOGY

In order to achieve economic power production from geothermal wells, it is necessary to effect long-lived, reliable completions. Currently, it is necessary to obtain a very competent cement bond between the casing and the formation in order to accommodate the thermal stresses that are induced in the casing during production of the well. Further problems involve the scaling of the borehole due to the high solids content of most geothermal fluids. Recent work has lead to an identification of geothermal casing failures modes. The analysis of thermal stress induced in the casing is presently underway using finite element computer models. Techniques for removing scale from the inside of the casing while the well is on production are under development. These descaling techniques involve the use of high-pressure cavitating jets to remove the scale.

SUPPORTING TECHNOLOGY

To support the development of the technology required in the above-mentioned areas, various research programs are being conducted. Of particular interest is the recent completion of a computer program called GEOTEMP which is capable of calculating the temperature of the drilling fluid at any point in the wellbore while drilling. In addition, the code can calculate the temperature of cement while the cement is being pumped into the well. These calculations are necessary to properly formulate the mud and cement during the drilling and completion operations. Once the well is completed, this computer model can be used to calculate the temperature in the produced fluid, as well as the temperature in the casing. Further supporting work is directed at developing new steel alloys which are corrosion resistant and can be used in drill pipe.

ADVANCED DRILLING SYSTEMS

In order to achieve well cost reductions of the order of 50% in the time frames scheduled for this program, the development of an advanced drilling and completion system will be required. A workshop that included industry, university and government participants was recently held to plan the development of the required system. The recommendations of this workshop have been published, and a program directed at implementing the recommendations has been initiated. Systems of primary interest are high speed downhole motors and bits, percussion drilling systems, and high pressure water jets used in conjunction with mechanical rock breakage techniques. Sandia Laboratories has initiated the development of these systems in conjunction with several industrial contractors.

THE RELATIONSHIP BETWEEN THE TEMPERATURE-GRADIENT DISTRIBUTION AND GEOLOGICAL STRUCTURE IN THE IZMIR-SEFERIHISAR GEOTHERMAL AREA, TURKEY

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Seferihisar geothermal area is situated coastal part of western Turkey. A great graben in which Quaternary volcanism prevailed, extends in a northeast-southwest direction in the area. Its southwest extension continues into the sea.

The basement of the area consists of metamorphites of the Palaeozoic Menderes Masif. The Upper Cretaceous İzmir Flysch was developed during the Mesozoic era. Yeniköy formation consisting of Miocene continental and lagoonal sediments, developed during the Cenozoic. Pliocene and Pleistocene Cumaovası volcanics transversing Yeniköy formation were also formed. These are made up of rhyolites and rhyodacites. Alluvium and hydrothermal alteration rocks developed during the Quaternary, are occupying extensive areas.

As a result of geological surveys, two geothermal regions were established in the area. The Cumalı-Tuzla geothermal region, controlled by tectonic features, contains numerous hotwater springs having comparatively high temperatures. These thermal fluids. are mixtures of local meteoric waters and thermally altered seawater. The other located around the rhyolite domes where Pliocene-Pleistocene acidic volcanism affected Miocene sediments. In this area a total of five low temperature springs were discovered. These are shallow waters.

During 1972 and 1973 a total of 18 gradient drill holes were opened in the Cumalı-Tuzla region southwest of Çubuklu Dağ graben and the temperature distribution within Graben-1 (Yeniköy formation) was determined.

Isogradient and isotemperature maps and temperature cross sections have been carried out by using these results.

The relationship between the geological structure and the isotherms can be well observed on the temperature sections. Geological structure determined during the geological surveys is further confirmed by these temperature sections which has many advantageous in the determination of the subsurface structure as well as geological setting of the reservoir. Furthermore, the ascending and descending direction of isotherms can be used to determine the thickness of the caprocks overlying the reservoir. It is proven that this kind of studies can be used directly to determine the location and the geological setting of the reservoir.

Studies carried out in the area show that İzmir-Seferihisar geothermal region has considerable geothermal potential. Because, gradient values in the anomalous areas were determined as 3,5 - 4,5 - 5 - 6 C°/10 m. while in the mid-zone they were determined as 2,25-2,75 C°/10 m. On the other hand, No G-2 gradient hole blew out at a depth of 85,45 m. in 1972. The temperature of water mesured in this hole at a depth of 70 m. was 137 C°.

As a result, thermal - gradient measurements are useful in large-scale regional surveys, as well as in specific reservoir studies.

HOT DRY ROCK GEOTHERMAL ENERGY DEVELOPMENT PROGRAM

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EXTENDED ABSTRACT

The overall objective of the Hot Dry Rock (HDR) Geothermal Energy Development Program is to determine the technical and economic feasibility of HDR as a significant energy source and to provide a basis for its timely commercial development, if warranted. Program motivation is derived from the enormous potential of the geothermal resource. Most all of this energy exists as heat in "dry" rock. If 2% of this resource could be economically recoverablle, it would be sufficient to provide the entire nontransportation energy requirements of the United States for over 2000 years at the present rate of consumption.

Principal operational tasks are those activities required to enable a decision to be made by FY86 on the ultimate commercialization of HDR. These include development and analysis of a 20 to 50 MW Phase II HDR reservoir at Site 1 (Fenton Hill) with the potential construction of a pilot electric generating station, Phase III; selection of a second site with subsequent reservoir development and possible construction of a direct heat utilization pilot plant of at least 30 MW thermal thereon; the determination of the overall domestic HDR energy potential; and the evaluation of 10 or more target prospect areas for future HDR plant development by commerical developers.

Supporting technology and institutional tasks will involve design and testing of advanced downhole instruments, equipment, and materials; drilling techniques; fracture studies; reservoir evaluation; engineering studies; regulatory studies to identify those factors necessary for widespread industrial utilization; and aggressive transfer of technology and information to industry, academic, and governmental organizations.

Progress to date includes the completion of Phase I of the Los Alamos Scientific Laboratory's Fenton Hill project. Phase I evaluated a small subterranean system comprised of two boreholes connected at a depth of 3 km by hydraulic fracturing. A closed-loop surface system has been constructed and tests involving round-the-clock operation have yielded promising data on heat extraction, geofluid chemistry, flow impedance, and loss of water through the underground reservoir between the two holes, leading to cautious optimism for the future prospects of private-sector HDR power plants.

SIMULATION OF GEOTHERMAL PRODUCTION

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The use of geothermal energy recently emerged as a significant contributor to the world's energy supplies. Already it provides more electricity than the world extracts from the sun's heat or from wind power. The most common available form of geothermal energy comes from the ground in the form of very hot water under high pressure trapped by an impermeable caprock above it. When a geothermal reservoir tapped by wells, the water rises to the wellhead, the pressure drops and the water flashes or boils. About 20 percent turns to steam, and the remaining hot water is seperated. The production of water from geothermal systems may result in ground surface displacements due to pressure drop in the reservoir and the surrounding rocks. The amount of compaction that a geothermal reservoir can have is a function of its reservoir characteristics. When both pressure and heat changes are small, the constant property assumption is justified. If, instead, pressure and heat drops show a wide range of change as in the geothermal reservoirs, rock and fluid properties have to be taken pressure and temperature dependent.

A literature review shows that there has been a number of studies to simulate geothermal reservoirs. Various researchers [1-5] have developed mathematical models and have employed finite-difference and finite element methods to obtain approximate solutions. In general, coupled equations for mass and energy balance have been solved either with association of stress equilibrium equations or by using simple elastic constititive relations. In this study we introduce a mathematical model to simulate the transport of heat and mass through a porous geothermal system, including the plastic heat dependent deformation of the reservoir produced by the stress changes due to production. First, the partial differential equations which describe the flow of water and the transport of heat in porous media are given as follows:

Flow equation:

$$\frac{\partial \epsilon}{\partial t} + \beta n \frac{\partial p}{\partial t} = \nabla\left(\frac{k}{\gamma_w}\nabla p\right) \qquad (1)$$

where ϵ is the strain, n the porosity, β the compressibility of water, k the hydraulic conductivity, p pore pressure, and γ_w the specific weight of water.

Energy equation:

$$\nabla(k_m \nabla T) - \nabla\left[(\delta c)_w\left(-\frac{k}{\gamma_w}\nabla p + n\frac{\partial U}{\partial t}\right)\right] = \frac{\partial}{\partial t}\left\{\left[(\delta c)_s(1-n)+(\delta c)_w n\right]T\right\} \qquad (2)$$

where k_m is the thermal conductivity, T the temperature, $(\delta c)_w$ the heat capacity of water, $(\delta c)_s$ the heat capacity of solid part of porous medium, U the displacement. These two equations couple through some solution dependent equation constants as well as explicitly shown dependent variables. In addition to these equations, a constitutive equation for the solid deformation is needed. This can be obtained by an associated flow rule for the temperature dependent plastic deformation.

$$d\epsilon_{ij} = d\lambda \frac{\partial f}{\partial \sigma_{ij}} + d\theta \frac{\partial f}{\partial T} \qquad (3)$$

where $d\lambda$ and $d\theta$ are proportionality constants to be determined. σ_{ij} denotes the effective stresses which are balanced by the pore pressure in the vertical direction. f shows the yield surface which is formulated as

$$f = \left[A(n)J_2' + B(n,T)J_1^2\right] - Y^2(n,T) \qquad (4)$$

where J_1 is the first invariant of stresses and J_2' is the second invariant of stress deviators. Y denotes the yield stress of the porous material.

Equation (1), (2) and (3) can be solved simultaneously by a numerical solution technique.

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TEMPERATURE INDICATORS FOR GEOTHERMAL WELL LOGGING

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EXTENDED ABSTRACT

A series of materials has been developed for temperature measurement in geothermal well drilling and logging applications. The solid to liquid first order phase transition associated with melting was chosen as the temperature indicator mechanism.

Initially, pertinent properties of some 15,000 substances were reviewed with regard to such factors as melting temperature, cost, commercial availability, lack of toxicological and ecological hazards, compatability with drilling fluids, etc. Following an initial screening, differential scanning calorimeter experiments were conducted on the most promising substances. These experiments included measurements of the sharpness of the melting transition and the heat of fusion. At present, 43 materials with melting temperature between 44°C and 351°C have been shown to be acceptable temperature indicators.

The temperature indicating process is based on the following. Depending upon the maximum temperature of exposure, certain of the indicators melt and others remain solid. Hence the maximum exposure temperature can be bracketed between the melting points of 2 adjacent members of the series. The configuration of the indicators has been chosen to provide an easy visual indication that an indicator has melted and re-solidified as compared with unmelted indicators.

The results of initial field tests on several candidate indicator configurations will be discussed. In these tests the materials were added to the drilling fluid at the surface, circulated down the drill string, through the orifices in the drill bit and a certain portion returned to the surface with the drilling fluid. Recovery of the temperature indicators was effected on or near the shale shaker. In some tests the materials were added to the drilling fluid just before a bit changing trip, and allowed to sit on or near hole bottom for several hours during the trip. Return to the surface is effected when drilling fluid circulation is resumed.

The results of the field tests, including indicator recovery statistics, loss of indicators by configuration failure, grinding by the drill bit, etc. will be described. Other geothermal applications and potential use of the indicators in oil and gas drilling will also be discussed.

SESSION 1E

UNUSUAL ENERGY CONVERSION

THE DEVELOPMENT OF A FREE-PISTON STIRLING ENGINE POWER CONVERSION SYSTEM FOR MULTIPLE APPLICATIONS UTILIZING ALTERNATIVE FUEL SOURCES

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ABSTRACT

Although the current world prices for petroleum-derived fuels are high, alternative energy sources such as synthetic fuels and concentrated solar radiation are available only at substantially higher prices. These clean energy alternatives can become economically viable in two ways. Either the prices of petroleum-based fuels and non-conventional fuels will equalize as the result of further increases in the world oil price and continued progress in supply technologies, or lesser amounts of fuel will be required to produce equivalent quantities of power as advanced, highly efficient energy conversion machinery is developed. It is this latter scenario which is developed in this paper.

The free-piston Stirling engine is an energy conversion device which has many features that can help to establish the economic feasibility of alternative clean energy sources. The engine employs an external heat source and is noted for its high thermal efficiency, simplicity, potential for long life with low maintenance, and quiet operation. The free-piston Stirling engine is hermetically sealed and has but two moving parts which are supported by non-oil lubricated gas bearings. Because of these features it is expected to be a highly durable power plant under various environmental conditions. The energy input to the working fluid is accomplished through external means; therefore, the engine can be used with a variety of heat sources in multiple applications.

This paper addresses the development of these power plants for several potential product applications, including synthetic fuel-fired heat pumps, electric

hybrid vehicles, and dispersed solar thermal electric power conversion systems. User economics justifying the utilization of high cost snythetic fuel and solar heat sources are presented. In addition, market penetration rate estimates are developed. The results support the high commercialization potential of such systems. An assessment of the state-of-the-art of free-piston Stirling engine technology is outlined in terms of currently available hardware. The design point efficiency, life data, and part load performance characteristics presented emphasize the strong potential for integrating free-piston Stirling engines with alternative clean energy sources so that cost effective systems result.

LOW TEMPERATURE ENERGY CONVERSION SYSTEM

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EXTENDED ABSTRACT

LOW TEMPERATURE ENERGY CONVERSION SYSTEM ENGINE

A low temperature 55-93 C (130-200 F) thermo-mechanical system had been demonstrated in Arizona. Various alternate energy sources such as solar collectors, geothermal wells or industrial process waste heat can furnish input energy. The prototype MARK I demonstrated the reality of the energy conversion process. However, additional development is needed to optimize the design and establish the economics of this innovative heat engine.

Operation The LTEC system has two closed fluid loops. In one, the working fluid, water, is expelled from a pressure vessel through a water turbine into another pressure vessel of equal volume. The collected water is returned to the first pressure vessel again through the water turbine completing the hydraulic working cycle. The second loop contains a refrigerant that expands by direct contact with the heated hydraulic working fluid. The refrigerant vapor fills the pressure vessel while expelling the water to drive the turbine. The expanded vapor then is vented to a refrigerant condenser as the hydraulic working fluid returns to the pressure vessel. The vented refrigerant vapor rejects its heat in a condenser. Condensed liquid refrigerant flows by gravity to an injection chamber. A quantity of refrigerant liquid is forced into the pressure vessel full of heated water to begin the expansion fluid cycle again.

The operation sequence of the engine shown in Figure No. 1 follows:

PV 1 is filled with water 55-93 C, inject refrigerant via SVL 5, expansion creates pressure within PV 1.

Water is expelled through CV 3, into turbine, through HX 1 and CV 6 into PV 2. Heat source for HX 1 can be solar, geothermal or waste heat. Rising water level in PV 2 displaces refrigerant vapor via SVG 4 to HX 2.

Vapor condensed in HX 2, flows by gravity to liquid receiver-injection chamber. (SV designates solenoid valves actuated by level sensors in the PVs.)

PV 2 is filled with heated working fluid. PV 1 is filled with refrigerant vapor. A controlled quantity of refrigerant liquid is injected into pressure vessel PV 2 via solenoid valve SVL 6. The refrigerant liquid expands to vapor and pressurizes PV 2, forcing water through check valve CV 4 into the turbine which discharges through the HX 1 and check valve into pressure vessel PV 1.

During filling, PV 1 is vented of refrigerant vapor to HX 2 via solenoid valve SVG 3. The refrigerant vapor is condensed in the refrigerant condenser HX 2. Cooling medium for HX 2 depends upon the available heat sink.

Filling of PV 1 continues until all the water is expelled from PV 2 and the expanded vapor fills PV 2. Solenoid valve SVG 3 closes and SVG 4 opens to vent PV 2 and permit the return of water from PV 1 into PV 2 via the turbine piping.

Analysis Operating temperatures assumed were 93 C for the heated water in PV and 43 C as the liquid refrigerant temperature. The latter can be obtained in the southwest during the summer months. The Carnot efficiency for the heat engine operating within these temperature parameters in 13.6%. Isentropic efficiency is estimated at 10% and overall efficiency at approximately 7%.

The Francis type wheel is rated by the fabricator for 4.4 KWe with a water flow of 318 lt/min (84 gpm) at a net head of 10.55 KG/cm^2 (150 psi). Isobutane (600 a) will develop a pressure differential of 11.96 Kg/cm^2 (170.18 psi) at operating temperatures with 50 C range.

Demonstration The prototype produced 1.2 KWe of electric power with input energy water heated to 55 C by a gas fired heater (heat source). A lamp bank of twelve 100 watt bulbs provides the electrical load. Additional testing is required to obtain data for optimizing the unit's limits and efficiency. Fig. 2 shows the Mark I prototype with 200 gallon pressure vessels and an evaporative air cooled condenser for the refrigerant vapor. Modifications for Mark II are being studied to have a compact continuous running system.

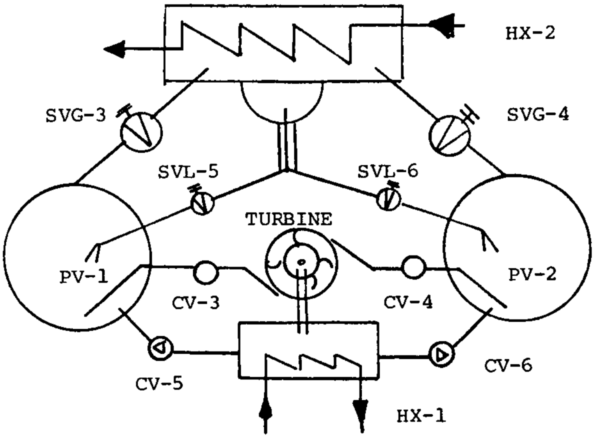

Fig. No. 1

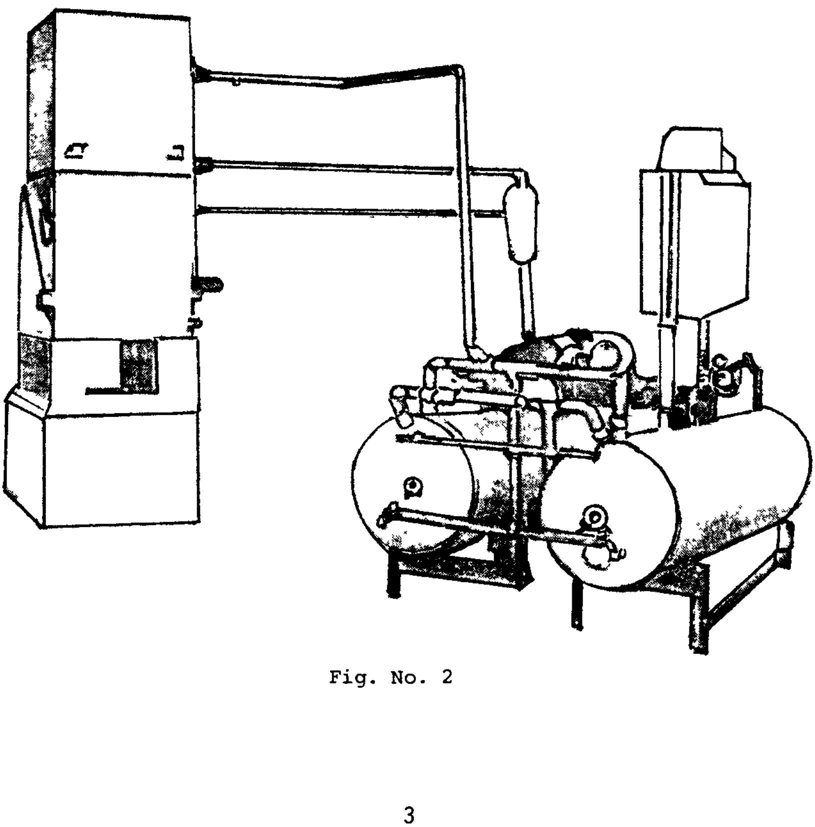

Fig. No. 2

A NON-CONVENTIONAL REVERSIBLE TOTAL ENERGY SYSTEM

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EXTENDED ABSTRACT

The purpose of this paper is to discuss the possibility of utilizing a non-conventional system called Thermogravimetric 1,2,3 as a total energy system. Characterized by a high ratio heat/energy, the thermogravimetric system develops a thermodynamic cycle at low temperatures with a consequent modest efficiency.

The vertical structure of the system, in relation to the extreme temperatures of the thermodynamic cycle and to the fluid employed, can vary between 30 and 60 m. This suggests that a 13-story building with 52 flats of 150 m^2 each might be used.

One of the peculair characteristics of the system is the possibility of using the thermogravimetric device as a heat pump inverting the thermogravimetric cycle. This is possible if we use a reversible hydraulic turbomachine as mechanical converter of energy. This possibility makes the thermogravimetric system particularly suitable to fulfill the thermal and energetic requirements of the user's seasonal and daily variations. There is the possibility of using several groups of plants in relation to the amount of heat and energy supplied by the system and required by the user.

Scaling, performance and economical evaluation are based on insolation data related to 40 degrees north latitutde and utilizing double-glaze, flat plate solar collectors facing south with a 30 degree angle of horizont.

A promising solution is the utilization of four groups of thermogravimentric systems so distributed:

a.) A main plant working as power generator of about 25kW able to generate through the condenser a water flow rate at 25C, enough both for heating and hot water. The energy supplied by this plant is about 50% of the energy required during insolation time by the user. For this purpose a collector surface of about 1000 m^2 is required.

b.) A reversible group working as a heat pump during the winter in order to supply part of the heat required by the building. This group works during the other months as power generator of about 30kW able to supply the 50% of the energy required by the user during daylight. With this plant that needs about 1000 m^2 of solar collector, the average energy required during daylight is supplied by the sun.

c.) A group working exclusively as heat pump during cold months. This plant of about 50kW supports the one mentioned above. A water flow rate at 60C necessary to the thermal requirements of the building is produced.

d.) A reversible group working winter daytime as power generator of about 25 kW and able to produce 50% of the energy required by the user during this period. The solar energy is collected by the flat plate collectors of the (b.) group that does not utilize them in winter. At nightime the processes are inverted and the plant works as a heat pump increasing the temperature of the hot water up to 50C. When the heating stops, this group works exclusively as a heat pump of about 40 kW and makes up for the reduction of heat caused by the stop of group (c.); hot water supply at 50C is assured again.

All these plants operate with satisfactory efficiency for a long working time as the efficiency of the thermogravimetric system is quite constant for a large variation of the load.

Different solutions aiming at reducing the number of the groups and consequently at varying the ratio energy-heat required/energy-heat supplied, are studied afterwards. A simplified evaluation of these solutions focus on their feasibility.

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SESSION 1F

ECONOMICS AND POLICY I

THE ECONOMICS OF NEAR-TERM ALTERNATIVES FOR COAL BASED ELECTRICITY GENERATION

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EXTENDED ABSTRACT

INTRODUCTION

A fourfold increase in the world price for oil imposed in the early 1970's by members of the Oil Producing and Exporting Countries (OPEC) took the world by surprise as the industrialized nations were unprepared either for the suddenness of the change or for its economic consequences. However, one direct consequence of the oil price increases which will be a long-term benefit to the world's oil consumers is the formation of the International Energy Agency (IEA). The primary objective of this organization is to foster the development of alternative sources for energy supply and to this end, a number of Working Parties have been established to examine research and development aspects of such energy alternatives as nuclear, solar, geothermal, and coal.

Under IEA guidance, a Working Party on Coal Technology was established in 1975 and its research program organization is presently located in London, England [1]. IEA Coal Research Activities are sponsored by 12 different countries and include seven projects which make up its total program. The study to be described in this paper was performed under the auspices of the Economic Assessment Service (EAS) whose ultimate objective is to define the economics of coal based energy both now and in the future by performing a technical and economic evaluation of coal conversion and utilization processes. This work is to include an evaluation of the future cost and availability of coal and the costs of transportation, utilization and conversion, and pollution abatement and control. As a part of this larger program, a technical evaluation of alternative base-load power generation processes based on the use of coal has been performed [2] and, more recently, this work has been extended to examine the economics of these alternatives [3]. The latter study is to be described here.

POWER GENERATION ALTERNATIVES

Anyone who has examined the literature dealing with coal conversion and utilization in recent years is aware of the large number of processes currently being developed throughout the world for coal based power generation. Thus in order for EAS to make meaningful evaluation of those processes, it was necessary to eliminate a large number of these alternatives from consideration by adopting a set of ground rules which excluded any process which failed to meet the following criteria:

i. To be considered, a process had to be technically far enough advanced to have reasonable chance of becoming commercially available before the mid 1990's.

ii. Each process chosen had to be undergoing development in plants of sufficient size that data were available which adequately described the technical aspects of the process.

iii. The process chosen must be suitable for base-load power generation applications.

The survey of power generation processes, within the context of the guidelines described above, resulted in the choice by EAS of the following systems for detailed evaluation:

i. conventional pulverized fuel boiler with steam cycle

ii. atmospheric fluidized bed boiler with steam cycle

iii. pressurized fluidized bed boiler with combined cycle

iv. integrated air-blown coal gasification with combined cycle

Systems are compared utilizing both a high sulfur coal with environmental regulations requiring 85% sulfur removal and a low sulfur coal without sulfur removal. The base case capital costs are set out for each of the alternative technologies under both coal feed type considerations and sensitivity studies are performed for various parameters of interest.

The conventional pulverized fuel system is considered to represent the state-of-the-art in coal utilization today, and as such it serves as a basis for comparing, not just other methods of producing electricity from coal but, indeed, all other coal-to-energy routes. A detailed analysis of the technical aspects of each of these four systems has been published recently by IEA Coal Research and the conclusions of that report will not repeated here. It will be sufficient to note that the previous work included a technical description of each process, a summary of typical performance data, and discussion of the relative advantages of each technology and process development problems presently being experienced [2].

ECONOMIC GUIDELINES

The capital costs for each process were derived from published North American sources containing costs for major plant items, and they include all elements of a grass-roots facility for the production of base-load electric power.

The numbers generated were compared with European estimates for pulverized fuel power generation in order to ensure applicability of the results to all IEA member countries. Furthermore, as the objective of the work was a technology comparison, the conclusions are considered valid across countries; though the absolute values of the derived costs would be expected to vary somewhat from country to country.

Derived capital costs also include an allowance for the uncertainty associated with new technology. This has been done by estimating a process contingency associated with each major plant item still under development and by evaluating the effects of these separate process contingencies on total plant costs for each alternative power generation system. Total capital requirements were then estimated reflecting three different assumptions: a design level corresponding to the capital cost without process contingency, a pessimistic level corresponding to the design level plus process contingencies, and a realistic level being a point mid-way between the first two.

Coal and other raw material consumptions, operating and maintenance costs, and process efficiencies were calculated on the basis of work carried out in previous IEA Coal Research/EAS work. A discounted cash flow analysis was carried out to derive electricity costs for each alternative under varying economic assumptions.

Comparative economics of the alternatives are presented by expressing the results of numerous sensitivity studies in terms of the percentage difference in electricity costs between the new technologies and conventional pulverized fuel generation. The effects of such variables as feed coal sulfur content, feed coal price, required rate of return, and duration of plant construction period on this difference in electricity costs are examined.

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THE ECONOMICS OF ADVANCED TECHNOLOGIES FOR ELECTRICITY GENERATION FROM COAL

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EXTENDED ABSTRACT

INTRODUCTION

This paper deals with base-load electricity generation from coal-fired power stations and compares the economics of four near-term alternative technologies:

i) a conventional pulverised fuel boiler with steamer cycle (PF)

ii) an atmospheric fluidised bed boiler with steam cycle (AFB)

iii) a pressurised fluidised bed boiler with combined cycle (PFB)

iv) an integrated air-blown coal gasification process with combined cycle (GCC) for a number of gasification processes.

Systems are compared for the combustion of both a high sulphur coal with environmental regulations requiring 85 per cent removal of sulphur from flue gases, and a low sulphur coal without sulphur removal. Base-case electricity costs are calculated for each of the alternative technologies with and without emission control, and the results of sensitivity studies are given for various parameters of interest.

METHODOLOGY

A self-consistent set of capital cost data were derived from published North American sources by comparison of the costs of major plant items against the costs of similar equipment for a conventional pulverised fuel system as the reference. These costs include all the elements required for a grass-roots facility producing base-load electric power Coal and other raw material consumptions, operating and maintenance costs were calculated on the basis of work carried out in previous Economic Assessment Service work [1,2] . A discounted cash flow analysis was carried out to derive electricity costs for each alternative under varying economic assumptions.

Comparative economics of the alternatives are presented by expressing the results of numerous sensitivity studies in terms of the percentage difference in electricity costs between the new technologies and conventional fuel generation.

SUMMARY OF RESULTS

From the results of calculations it appeared that when burning high sulphur (3.5%) coals with environmental regulations requiring 85% sulphur removal, the advanced technologies could generate electricity 13 - 15% more cheaply than conventional pulverised fuel combustion with wet limestone scrubbing. The magnitude of the reduction in electricity cost varies differently with rate-of-return and coal cost for each system, depending on the relative contributions of capital and coal requirements to the cost of electricity. Detailed comparisons indicate that none of the advanced systems has a clear advantage over its rivals, but that the most economic alternative depends on coal price and rate-of-return. Thus the AFB system is the most economic at coal prices up to \$1.0/GJ at a 5% dcf rate-of-return and up to \$1.7/GJ at a 10% dcf rate-of-return. At both rates-of-return the Texaco and the General Electric gasification/combined cycle systems (the most favourable of the gasification systems considered) generate electricity somewhat more expensively than the PFB system. For power stations burning low sulphur coals without emission controls, the costs savings of the advanced technologies over pulverised fuel generation is only of the order of 5-6%.

The sensitivity of the above results to a number of parameters was examined. Because the combined cycle systems have scope for plant modularity, the effect on generating costs of reducing plant construction times from four to six years was considered. It was found that this reduced electricity costs by 0.3 mills/kWh at 5% dcf rate-of-return and by 1.2 mills/kWh at 10% dcf rate-of-return for the low capital cost PFB system (\$507/kWe - mid 1977 dollars) and by 0.4 and 1.5 mills/kWh respectively for the more expensive Lurgi gasification combined cycle system (\$662/kWe). Given the assumptions made this reduction is sufficient to make the PFB system with a construction period of four years the preferred option for power generation from all but very cheap coal (ie, less than about \$0.5/GJ).

The above conclusion is based on Ca/S mole ratios for sulphur removal of 1.5 for PFB and 3.5 for AFB (as currently predicted from small-scale units). A sensitivity analysis of this parameter indicated that either the failure of PFB to achieve such an efficiency or an improvement in the sulphur retention of AFB combustion in a commercial-scale facility would considerably improve the competitive position of AFB, particularly for low-cost coals.

Finally, since there is a greater or lesser element of doubt about the cost/performance data of all the advanced technologies considered, the sensitivity of electricity costs to an escalation of capital cost was examined. The results were expressed in terms of the level of escalation (%) at which the cost of power generated from high sulphur coals would become equal to that from a conventional pulverised fuel station with a wet lime scrubber. However, as these processes are at different stages of development, it would be expected that the levels of cost escalation will vary from process to process. The 'break-even escalation' varies with coal cost and rate-of-return, but for a 10% dcf rate-of-return is about 15% for Lurgi gasification/combined cycle (four year construction period), about 40% for the Texaco or General Electric gasification/ combined cycle systems (four year construction period), about 50% for AFB (Six year construction period) and about 60% for PFB (four year construction period).

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ALTERNATIVE ENERGY AND THE POOR

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ABSTRACT

This paper assesses local, state, and federal programs in alternative energy/technology development as they relate to the direct and indirect energy needs of the poor. A multivariate analysis of energy consumption patterns among the different populations comprising the "poor" is presented, as are projections incorporating various alternative energy inputs resulting from current programs.

The data support the conclusion that local, state, and federal programs relating to alternative energy, if maintained at present levels, will have no significant impact on most of the populations characterized as poor, and minimal impact upon the others. The need for expanded and sociologically informed programs in alternative energy development is asserted.

EMPLOYMENT ASPECTS OF ENERGY POLICIES

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A number of energy-related parameters are to be examined when the problem of energy systems is faced in order to find satisfactory solutions in the long run.

Satisfaction being connected with the fulfillment of the main economic and social expectations about the quality of life, employment aspects of energy policies should be considered.

The dynamics of employment are usually examined in terms of industry committement. From this point of view, the most relevant effects are induced by the fact that the energy systems tend to become more and more capital intensive.

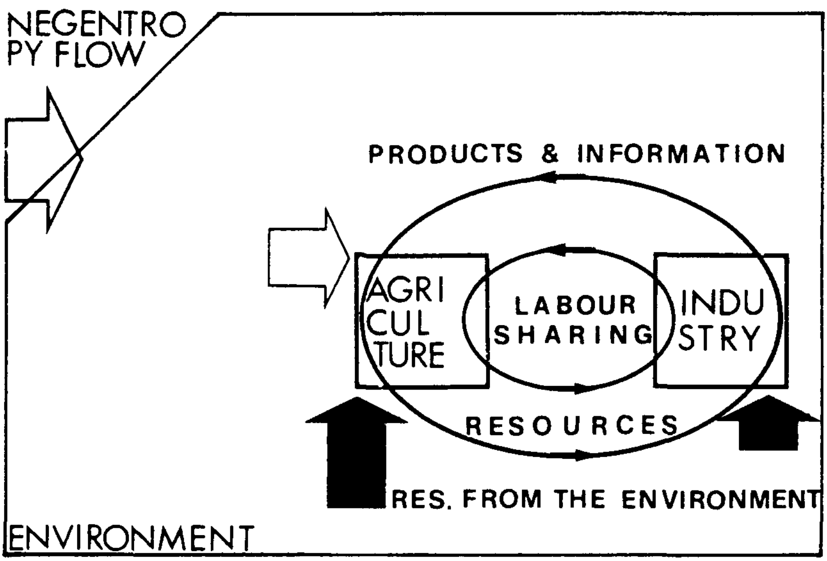

Fig. 1
The rural alternative

Conservational needs, together with the shifting of interest from non-renewable to renewable resources, are the roots of this structural changing. However, other important changings are find to affect the labours sector, if a more complete analysis of the labour-energy interrelationships is set up.

The base conditions for survival (food and environmental quality included) are still under discussion. Entropic considerations about the future production systems and the environmental constraints, being added to the usual energy balances, the shifting of a certain number of workers into agricultural jobs is find to be desirable.

In fact, the agriculture system characteristics are fitting with the main future requirements on the subject of renevable resources exploitation, conservation and/or restoration of the environment, and waste recycling processes. Accordingly with the Fig. 1 scheme, the design philosophy of a suitable, innovative structure for the agriculture systems is outlined.

The rôle of small multipurpose and multiburce energy plants, together with the improvement or the invention of nonconventional techniques, applied to the control of the biological processes as well as to the transforming systems is emphasized, and the systems size and communication problems are examined.

Assuming that the project feasibility depends on the creation of some necessary facilities, the energy gain versus the cost of the system plus the facilities is used as the optimizing concept for the final structure.

The resulting changings within the labour sector are find to be induced not only by the increasing of agricultural jobs, but also by the increasing of the informational devices requiremants.

An attempt is made to provide the means for a provisional estimate.

SESSION 2A

SOLAR COLLECTORS II

CONVERTIBLE, TRI-MODE SOLAR CONVERSION SYSTEM

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EXTENDED ABSTRACT

INTRODUCTION

There is now a real and growing need for cost/effective solar conversion hardware with combined modes of operation for effective year-round solar energy utilization. Individual homeowners are still generally reluctant to invest in the installation of solar energy units when faced with extensive retrofitting requirements and doubts about the year-round effectiveness of suitable equipment, in spite of ever increasing monthly fuel costs.

When the average homeowner realizes that he does not have suitable near-south facing walls and roof lines, he may lose interest in solar without considering that the backyard may offer an ideal area for a solar conversion installation.

The flat roof tops of apartment houses and many urban commercial buildings will provide an ideal site for the highly efficient concentrator conversion systems which can produce several modes of solar conversion on a year-round basis.

BACKGROUND

The convertible, tri-mode solar conversion system has been evolved to provide year-round solar conversion with three distinct modes of operation. The basic concept behind the development of this tri-mode system is quite simple. Make all the solar conversion hardware work as hard as possible year-round to improve the cost/effectiveness and attractiveness of solar conversion, especially for the northeastern area of the United States.

The key to the effectiveness of the combined mode of operation concept is that the same basic components must be partially useful for both winter and summer solar conversion without having to introduce completely new components with proportionately increasing costs. To be specific, linear parabolic concentrators should provide both wintertime hot air for space heating and summertime water/steam to electric power generation, so the system investment may be amortized within a relatively short period of time.

DESCRIPTION

The convertible, tri-mode solar conversion system utilizes two basic types of solar conversion hardware. The first being conventional linear parabolic concentrators which are made up in six-foot long sections for convenience in handling and installation. The linear sections are joined together in-line and in groups of three to produce high conversion temperatures at the focal line. The linear concentrators provide both heated air through focal zone transparent ducts and hot water/steam from conventional focal line piping.

The second basic component is the hot box solar collector and storage unit which is designed to both collect and store solar thermal energy during the winter months. See Fig. 1 and Fig. 2.

The two basic component types cooperate to both collect and store solar energy during the winter months, while the linear concentrators produce hot water/steam during summer and the hot boxes store solar heated water.

TRI-MODE OPERATION

The three modes of operation provide hot water service and hot water storage year-round. Hot air for home or building space heating is provided during the winter with conversion to hot water/steam for electric power generation during the summertime.

Summer steam is produced in the focal piping within the full length of all concentrator sections. This steam is directed into a simple shee metal turbine which is connected to and drives a suitable electric alternator at 60Hz. The steam flows within a conventional closed-loop Rankine cycle and is condensed within condensers or radiators.

Wintertime hot water is produced within this same forcal piping with hot air provided through a thin, double surface plastic duct which is concentric to the focal piping. The thin plastic duct is supported by spirally wound wire coils with uniformly located radial struts fastened to both the focal piping and the wire coil forms. Valves are provided at the ends of the concentrator sections to open and close the two fluid flow loops depending on the specific mode of operation required by the seasons of the year.

INSTALLATION SITES

This combined tri-mode solar conversion system is obviously not adaptable to most peaked roofed homes, but is ideally suited to flat roof top apartments houses, homes, commercial buildings with flat roof tops. Another suitable type of installation will be for homes with yard or ground space of homes and property with an unobstructed exposure to the sun during most of the day.

HOT BOX MODIFICATION

Although the hot boxes used for this system application are basically conventional units with large area double-glazed front entrance windows, the units are modified to provide reflected solar ray entrance under the front main window.

A large reflective field area is located in front to the sides and under the unit to effectively direct reflected solar radiation up into the unit.

The combined direct and reflected solar insolation on the units will aid in maintaining relatively high temperatures during sunny winter days.

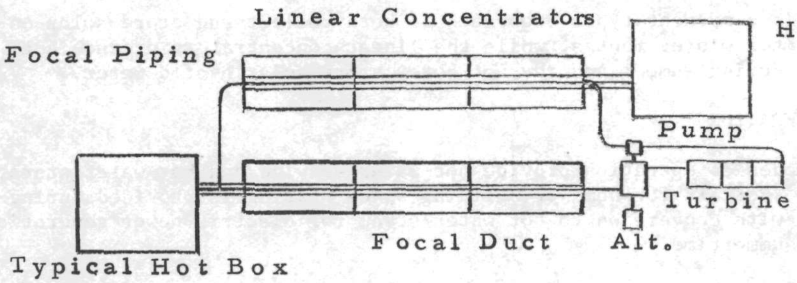

Fig. 1 - Schematic of System

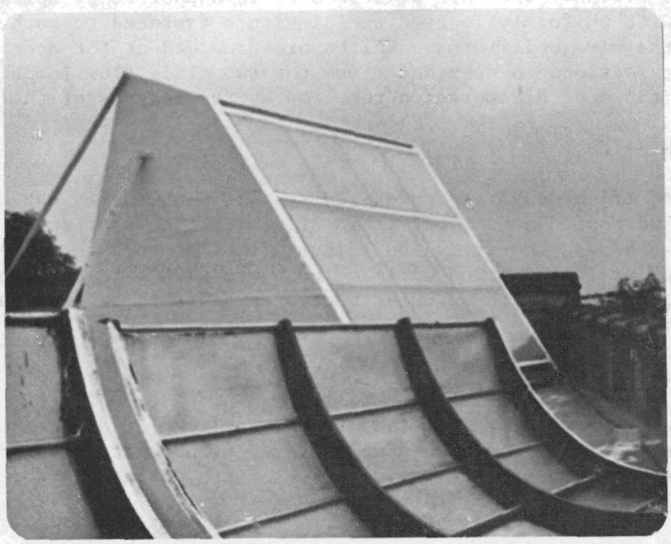

Fig. 2 - Convertible, Tri-mode Solar Conversion System

 DAK

A FIGURE OF MERIT FOR SOLAR COLLECTORS WITH SEVERAL SEPARATE ABSORBER SEGMENTS

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EXTENDED ABSTRACT

INTRODUCTION

A figure of merit for solar collectors is presented and examined. The main purpose of obtaining a figure of merit is to aid in comparisons of collectors having several thermally separated absorber segments. Nevertheless, the results are useful for single absorber collectors.

The proposed general figure of merit, Q, has information about the input distribution, the concentration and the acceptance function built into its definition. In addition, we propose the use of a channel matrix to characterize a collector. The channel matrix enables the figure of merit to be readily calculated for various input distributions.

DISCUSSION

There are three factors that influence a collector's performance, in addition to the factors that depend on what the concentrator is being used for, i.e., high or low operating temperature. These three factors are the input distribution of radiation, the concentration, and the acceptance function, I (θ).

The input distribution is given and is the same for concentrators under comparison. Nevertheless, the input distribution determines how the other factors are weighted in the total collector performance. For example, a concentrating collector offers no advantage over a flat-plate collector if the input radiation is isotropic.

The concentration is an indicator of collector performance. There are at least two definitions of concentration. The geometric concentration is the ratio of the aperture area to the absorber area; it can have any positive value. The optical concentration is equal to the geometric concentration times the fraction of rays within the collecting angle that get transmitted to the absorber.

The acceptance function, I (θ), is defined as the probability that a photon having an incident angle of θ at the aperture strikes the absorber.

The usual theoretical method of comparing concentrators is to specify the geometric concentration and the acceptance function. We know of no procedure for combining these factors into one figure of merit. As a result, it is impossible to determine which concentrator will perform better if these two factors contradict one another. Therefore, experimentally determined efficiency curves for collectors are necessary. Furthermore, the effect of the input distribution is ignored.

We propose Q as a general figure of merit, where

$$Q = \sum_j b_j Q_j \quad . \tag{1}$$

The index j labels each separate absorber segment. b_j is defined as the probability that a photon, after having entered the aperture, strikes the jthe absorber segment. Q_j is defined as

$$Q_j = \frac{A\, b_j}{\sigma_j} \quad , \tag{2}$$

where A is the aperture area and σ_j is the area of the jth absorber segment.

Q_j is equal to the geometrical concentration only if b_j equals unity. Q_j can be considered another definition of concentration. It is the geometrical concentration times the fraction of the total radiation entering the aperture that strikes the jth absorber. Q_j appeals to intuition; for example, if Q_j has a value of four it means that the radiation striking the jth absorber is four times as intense as the radiation entering the aperture. A value of four for Q_j represents greater intensity then an optical concentration of four because Q_j includes diffuse radiation in its definition. If the input radiation is isotropic, the maximum value of Q_j is one, whereas the optical concentration can be very large.

Q is the mean of the set of Q_js, where each Q_j is weighted by b_j. Therefore, Q can be considered an average concentration that is representative of the collector as a whole.

Each collector can be represented by a channel matrix. The input distribution and the channel matrix determine the sets $\{b_j\}$, $\{\sigma_j\}$, and the resulting figure of merit. The channel matrix enables the effect of various input distributions to be computed easily.

The figure of merit is tested by examining ten hypothetical cases. The results are compared with the exact results for several different flow rates of the working fluid, where exact results are obtained with the use of the standard flat plate efficiency equation. The figure of merit rating were found to be in general agreement with the exact results. A practical example is given.

CONCLUSION

We believe the figure of merit is a quick and easy method for comparing collectors when a general indication of performance is needed. A value of Q somewhat greater than one indicates a significant improvement over a flat-plate collector.

THEORETICAL AND EXPERIMENTAL INVESTIGATION OF A FLAT-PLATE SOLAR COLLECTOR PERFORMANCE WITH THE USE OF A SOLAR SIMULATOR

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EXTENDED ABSTRACT

Collector tests are either performed outdoors on clear days near solar noon, or indoors using an artificial source of light (i.e. a solar simulator). The latter is the method partly used. This paper investigates the thermal performance of a flat-plate collector theoretically and experimentally by the use of a solar simulator.

The solar simulator consists of 24 tungeston halogen lamps, 1000 W each, placed in 8 rows and 3 columns. The simulator area is approximately equal to the absorber area of the collector. The collector consists of an absorbing steel plate, black painted, and 6 parallel copper tubes and are metallically bonded. A small centrifugal pump has been used with approximate energy input of 55 W to ensure circulation of water through the tubes and 0.005 kg/s mass flow rate has been used.

The efficiency equations that applied was expressed as follows:

$$\eta = (\alpha\tau)_e - \frac{A_c}{A_e} U_L (\bar{T}_p - T_a)/I \qquad (1)$$

and $$\eta = \{ \dot{m} c_p (T_{fo} - T_{fi}) - 55\} /I \qquad (2)$$

Where A_c and A_e are respectively the absorber and effective areas of the collector.

Collector tests has been considered for single and double glass cover of 4mm thickness and 4cm appart at values of 0, 1.5 and 2.6 m/s wind speed. Results has been obtained for a ranges of radiant flux from 300 to 1080 W/m^2 and indoor temperature from 39 to 43.5^{o}C.

Figure 1 shows the predicted performance curves for a single glass cover at different values of wind speed from 0.0m/s to 2.5 m/s. It can be seen that by plotting efficiency against temperature difference divided by radiant flux {η against $(T_p-T_a)/I$} , the collector parameter are obtained from the slope and the intercept of the curve with Y-axis, where the slope is equal to overall loss coefficient, U_L, which is a measure of heat loss and the intercept which is equal to $(\tau\alpha)_e$. It is clear that the performance curve of 2.5 m/s wind speed has poorer performance than that of zero wind speed. The figure also shows that increasing the wind speed, increases the slope, i.e. higher heat loss, and decreases the intercept with Y-axis, i.e. less absorption of radiant flux.

Figure 2 shows the experimental characteristic curves for single and double glass cover at 1.5 m/s wind speed. The effect of increasing the number of cover is to decrease the heat loss from the collector to the surrounding and also lower the cover transmittance.

Figure 3 shows a comparison between theoretical (at $0^o$and 53^o incident angle) and experimental performance curves of single cover at 1.5 m/s wind speed. The experimental performance curve is much agreed with the theoretical curve at 53^o incident angle. Increasing the incident angle gives less value with the Y-axis.

Figure 4 shows a comparison between theoretical (at 0^o and 53^o incident angle) and experimental performance curves of double cover at zero wind speed. It is clear that both experimental and theoretical at 53^o are very close to each other.

DEVELOPMENT AND STUDY OF A FLAT MIRROR MULTIVALENT CONCENTRATOR

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EXTENDED ABSTRACT

I. PURPOSE OF THE DESIGN

This concentrator has been designed as a laboratory apparatus rather than an industrial product. Its price is about \$ 4000. It would be able to reach a temperature of 300°C with a geometrical concentration ratio $\mathcal{C} = 60$. Its possibilities would be as follows :

1°) Study of the behavior of a solar receiver with a mean concentration ratio under random conditions of insolation(mean yearly insolation ratio : 0,4 in Lyon).

2°) Testing of different boilers to find the best shape giving the highest yield.

3°) Studies of thermo electrical generators and hot air machines.

4°) Experiments on drying material by hot air or overheated steam, on pyrolysis or distillation.

5°) Production of cold by use of heat pumps and absorption pumps.

II. DESCRIPTION

1°) <u>The concentrator</u>. The square reflecting area measuring 2m x 2m is made of 64 plane square mirrors, 2.5 cm on side. The four central mirrors are hidden by the furnace. The effective concentration ratio is $\mathcal{C}_e = F.\mathcal{C}$, F is the "furnace ratio" whose value usually is 0.6. So, $\mathcal{C}_e \simeq 36$; if the solar intensity is 850 $W.m^{-2}$, the theorical maximum temperature is 580°C. In practice, a 300°C temperature should be reached. It is easy to show that the slope of each mirror to the horizontal plane must be $\theta/2$ if θ is the angle of the axis of the concentrator to the axis of each mirror (fig. 1).

The focal spot is situated on a plane which is parallel to the plane xO'y, whose altitude is h (h = 1.8 m).

The form of the focal spot is given by fig. 2

The power received by all the mirrors is about 3 kW. One may hope to recover the half of it on the furnace.

2°) <u>The furnace</u>. It is a tubular copper boiler with a thermal screen inscribed in a square covering the four central mirrors exactly. Thermocouples are attached in several points allowing estimation of thermal losses.

3°) <u>The mounting of the concentrator</u>. An equatorial mounting has been chosen. The solar receiver is made of three separate parts : a fixed part : the chassis ; a first movable set sloped at the latitude of Lyon ($\varphi \approx 46°$):

the cradle ; a second movable system supporting the mirrors and the furnace. Within the cradle, a parallelepipedic frame is turning, whose bottom bears the mirrors and the superior part, the furnace. The frame may be adjusted with the declination so that the symmetry axis of the system always remains pointed towards the sun.

III. TRACKING DRIVE CONTROL OF THE APPARATUS

We have chosen a "blind" tracking that is to say that the system is oriented according to the data directly calculated from the equations of the movement of the earth around the sun. Its advantage is to be directed always towards the sun, so that the time of insolation is maximum even if the apparition of the sun is intermittent. A D.C. motor is used, mounted on an important reductor. The control is made by means of a feedback loop with an angular detector directly mounted on the shaft of the solar concentrator. The automatism is acted by numerical means with a hit - or - miss governor. The command organs include :
a) The instructions. The angular variation instructions of the system are assumed by a digital clock working with the electric network. The angular increment is settled to be 1° ; this leads to a displacement of the concentrator every fourth minute. A divisor allows to obtain this signal which is transmitted then to a binary counter. At each instant, the counter owns the instruction value, translated into an angular one.
b) The feedback loop of the control is assumed by a potentiometer. The potential difference, proportionnal to the angle it delivers, is converted into numerical data by means of a digital-analogic converter.
c) The command of the motor. The informations issued from the counter and the converter are analysed in a numerical comparator which pilots the on-off relays and those of the sense of rotation.

IV. CONCLUSION

Such a converter will be able to be used in a lot of studies involving the utilization of the direct solar radiation, particularly in countries which are not very favoured as for the insolation, like the lyonese one.

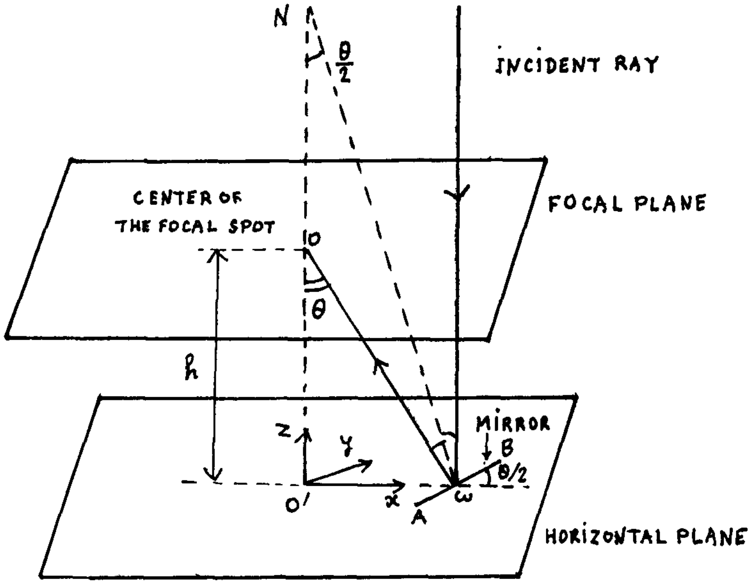

Fig.1 Position of an elementary mirror

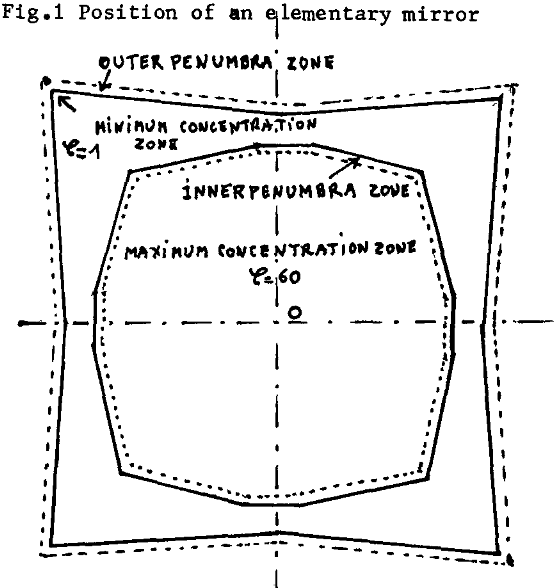

Fig. 2 Approximative shape of the focal spot. Scale 1/4.

STATIC ENDO-ABSORBENT FLAT SOLAR COLLECTOR

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EXTENDED ABSTRACT

INTRODUCTION

The possibility exists of absorbing the solar radiation by means of micro-absorbers completely immersed in a heat transfer fluid. In this case all heat leaving the micro-absorbers by convection heat transfer goes necessarily into the heat transfer fluid in contrast to a conventional flat-plate collector where some heat is lost without entering the heat transfer fluid.

It is shown that such a possibility, which we will term the endo-absorbent concept, allows not only for a higher efficiency but also for several other advantages when compared to a traditional flat-plate collector concept.

THE ENDO-ABSORBENT CONCEPT

In this paper, endo-absorption refers, as stated above, to the absorption of solar radiation by discrete micro-absorbers which, although of a wide variety of sizes and geometrical configurations, are completely immersed in the heat transfer fluid. Therefore, designs such as that of the overlapped-glass plates or that of a blackened metal screen are not included in this definition.

Static endo-absorber. The first realization closest to the concept was that of the so-called black liquid solar collector (1,2,3,4). In this case the micro-absorbers are carbon-black particles, or other suitable material permanently dispersed in a medium such as ethylene glycol-water mixture. This mixture constitutes the heat transfer fluid for this type of collector.

The concept proposed here as the static endo-absorbent concept is that one in which the micro-absorbers although immersed in the heat transfer fluid are not permanently dispersed in it but are rather at rest or moving around or vibrating within the solar radiation absorbing volume. Consequently, the micro-absorbers are kept within the limits of this volume while the heat transfer fluid circulates through it.

DESIGN CONSIDERATIONS

The basic unit we are considering here, among other possibilities, consists of a glass or plastic tube transparent to solar radiation which contains certain small amount of micro-absorbers. The micro-absorbers may be particles of a wide variety of materials, configurations and sizes such as small spheres of a blackened plastic, for example. The particles are of such characteristics as to be dispersed filling the entire radiation absorbing volume of the tube as long as the heat transfer fluid is passing through it but sedimenting towards the bottom of the tube as soon as the fluid stops circulating. To prevent the particles from being dragged away by the circulating fluid a special filter or suitable trap is provided at the ends of the tube.

In another realization, the same tube as before is almost completely filled with micro-absorbers which in this case are of a larger size and density than in the previous one. This allows for the suppression of the special filter or trap at the ends of the tube. However, as friction may result very high a heat transfer fluid of lower viscosity such as air could be used.

The complete collector consists of an array of such tubes attached to a main conduit carrying the transfer fluid.

Other design considerations such as glazing, insulation, number of cover plates and framing are the same as in a conventional flat-plate collector and will not be discussed here.

THERMAL ANALYSIS

From the energy balance equations for a basic unit the well known expression (5,6)

$$I_u = F' \left[I_a - U_l (T_f - T_a) \right]$$

is obtained, where I_u is the useful energy obtained, F' the absorber efficiency factor, I_a the solar energy absorbed, U_l the overall heat loss factor, T_f the average fluid temperature and T_a the average ambient temperature.

In our case F' can be taken equal to 1 while for a tube-and-fin design is always less than unity as it is well known.

On the other hand, the effective transmittance-absorptance is in general higher than for a conventional flat-plate absorber for the absorptance is not only almost constant for any angle of incidence but it is also very close to 1. Furthermore, in a tubular design of the basic unit as proposed, absorption conditions are not so dependent of the position of the sun. All these factors bring a substantial improvement in the efficiency for a collector of this type.

RESULTS AND DISCUSSION

When compared to conventional flat-plate solar collectors, those of the type discussed here present the following important advantages:

a.- Greater efficiency. An extra 10 to 15 % is achieved.
b.- Since no metals are needed in the active sections, an important reduction in cost is obtained while at the same time corrosion problems are eliminated.
c.- Construction problems are simplified or eliminated.
d.- Due to the above mantioned reasons, final cost is substantially reduced not only in terms of cost per unit collector area but also due to the smaller total collector area needed as a result of its better efficiency.

Furthermore, the static endo-absorbent concept presents the following additional advantages:

a.- Designs are possible for both air or liquid heat transfer fluid.
b.- No heat exchanger is always necessary. This could result in an extra reduction in cost for a given installation.
c.- No sedimentation problems are to be taken into account with improved maintenance and system simplification.
d.- Much greater flexibility when selecting material, size and configuration of the micro-absorbers.

The basic unit described although suitable as a component of a flat-type collector presents very good characteristics for receiver in a focusing-type collector.

Further research is being carried on for the proper optimization of this type of collector.

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EVALUATION OF SOLAR COLLECTOR PERFORMANCE WITHOUT FLOW MEASUREMENT.

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ABSTRACT

An experimental study of the no flow or calorimetric method of measuring solar collector and ducting thermal losses has been/ performed on a flat plate collector with an area of 25 m^2.The collector is part of a small prototype solar engine. Water temperature readings are taken at half-hour intervals at four locations: collector inlet and outlet, heat exchanger outlet and temperature stabilizing reservoir outlet. Measurements are carried out over periods of twenty four hours, both with thermosyphon water flow through the circuit and in the no flow condi-/ tion. The corresponding incident solar radiation intensity was also recorded. On the basis of these data and from the water / volume contained in various parts of the water circuit, esti-/ mates are obtained of collection efficiency, heat loss coefficients and water mass flow rates for different sections of the system. The method is of particular interest for testing small solar power plants in rural areas, since it dispenses with the need for relatively sophisticated instruments except for solar radiation intensity or solar rediation income in each half / hour period.

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AN ALGORITHM TO ESTIMATE LONG TERM SOLAR FLUX INCIDENT ON A PLANE ANYHOW ORIENTED SURFACE

Abstract - Monthly averages of daily global solar radiation incident upon a horizontal surface are available for many locations and often for many years. Such data are the base for long-term thermal performance evaluation of solar systems. We present an algorithm which, from this data, lead to an estimate of monthly average daily solar energy incident upon plane anyhow oriented surface. The method is based on the following steps : i) estimate of monthly avareges of daily diffuse from daily global radiation experimental data for an horizontal surface, ii) calculation of the ratio of direct flux on the tilted surface to that on the horizontal surface by integration, iii) evaluation of diffuse and reflected fluxes incident on tilted surface, iiii) summation of the three components of the global flux. The limits of integration needed in the second step require the analysis, rather laborious, on possible direct irradiation periods for plane anyhow oriented surface and for any latitude. This analysis is expounded almost in detail since it seems that this problem has not been suitably exposed in literature. We present results for some significant cases: surfaces facing due south with a tilt angle equal to latitude or ten degrees grater, vertical surface with principal orientations. Comparison of those results with differently evaluated data available in literature show the existing good agreement. The proposed algorithm seems, for its inherent plainnes, to be suited for desktop calculators.

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CALCULATION OF HOURLY AND DAILY AVAILABLE SOLAR ENERGY TO FLAT PLATE COLLECTOR INCLINED BY THE ANGLE OF OPTIMUM TILT IN IRAQ

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EXTENDED ABSTRACT

The maximum solar energy available to an inclined flat plate collector is estimated by predicting the values of a conversion factor, R, which is the ratio of total solar radiation on a tilted plane to that on the horizontal plane. This factor is calcualted for each hour and day and presented graphically as a function of collector tilts, hours in the day and months of the year.

Verification of the results obtained for R has been carried on for several months of the year using the CM8 Kipp and Zonen solarimeter. The empirical and the estimated data are found in agreement.

Illustrating case is explained taking the optimum tilt for the collector durin g the months of the year, secured from the above mentioned graphs of R, to predict the maximum solar energy available to the optimum tilted flat plate collector.

An exponential graph has been introduced to predict the value of the conversion factor, R, at any time for the optimum tilt angle at that time.

SESSION 2B

PHOTOVOLTAICS II

A STUDY OF COMBINED (PHOTOVOLTAIC-THERMAL) SOLAR ENERGY SYSTEMS

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EXTENDED ABSTRACT

INTRODUCTION

The overwhelming majority of structures, be they private residences, retail outlets, or manufacturing facilities, require both thermal and electrical energy. Study of the available literature indicates many reports concerning systems providing solar thermal energy and many others dealing with photovoltaic sources - but generally as separate entities.

This paper is devoted to a theoretical analysis of a combined system. Incoming light is concentrated using lenses and allowed to fall on the solar cells which then generate electric power. The energy rejected by the solar cells (~80% of the insolation) is available to heat the thermal energy collection mediam and delivered to the load requiring heat energy. Several levels of optical concentration are studied with an upper limit imposed by the rapid decrease in solar cell efficiency with increasing temperature and the increasing difficulty of accurate manufacture and operation with increasing concentration.

The combined system chosen utilizes either silicon or gallium arsenide solar cells. The latter are more efficient, but much more expensive. In view of the large member of possible thermal loads each with highly specific characteristics it has been decided to provide a rather general system using a fluid such as pressurized water as a thermal energy transfer medium and taking as the overall thermal efficiency the Carnot efficiency less 10% (the 10% allowing for pumping losses as well as the non-ideal nature of all thermal systems).

TEMPERATURE AND PHOTOVOLTAIC CONVERSION

With load optimized the maximum solar cell efficiency, η, is: [I].

$$\eta_{max} = \frac{(J_{ph} + J_s)\ (n V_D) V_D}{(n V_D' + 1 + k')} \left(1 - \frac{k'/2}{1+k'}\right) \quad (1)$$

Where: J_{ph} is the current density resulting from photon-electron-hole pair conversions within the cell, J_s is the doide saturation current; λ is the electronic charge, q, divided by the product of the absolute temperature and Boltzman's Constant; n is the diode ideality factor which can be shown to be unity for junction diode solar cells in concentrator systems [II]. V_D' is the solar cell junction voltage for optimum power transfer; and k is the solar cell loss factor given by:

$$k = 2 r_D (J_s A)(\lambda/n) \exp[\lambda V_D'/n], \quad (2)$$

where r_D is the solar cell internal resistance, and A is the solar cell area.

For a given system values of k and V_D' can be found by solving equations (2) and (3):

$$[\frac{\lambda}{n} V_D' + 1 + k] \exp[\frac{\lambda}{n} V_D'] = (J_{ph} + J_s)(1 + k)/J_s. \quad (3)$$

There are many kinds of solar cells and solar cell configurations [I] and the possible variations effect many of the parameters in the preceding equations. For this paper I have chosen the following solar cell systems as being most closely approximated by systems either (1) currently in existance or (2) capable of production in the near future.

Optically Concentrated	-	Fresnal lens
Junction	-	PN Junction
Configuration	-	Vertical Junction [III]
Material	-	Silicon or GaAs
Cooling	-	To be treated in the following section.

For the chosen solar cell system temperature will have a neglible effect on the diode ideality factor, area and diode series resistance. Allowing for the temperature effect on J_s one can calculate the change in solar cell efficiency for a given solar cell configuration. These results for silicon and GaAs solar cells are presented.

THERMAL ENERGY TRANSFER SYSTEM

The thermal conversion portion of this system has two functions to perform. It must supply heat energy to the thermal load and must cool the solar cells. Any thermal system is subject to losses involving pumping the transfer fluid and thermal leakage. Both depend on the configuration of the system which in turn is a function of the load and solar concentrator configurations. Rather than assume each a system, which would be highly specific, let us assume that the entire thermal system is a simple heat engine. Such a device does have a maximum efficiency - that of a carnot engine with efficiency

$$\eta_c = (1 - T_c/T_H) \times 100, \quad (4)$$

Where T_c is the temperature of the cold heat reservoir and T_H that of the hot heat reservoir. We cannot expect that any thermal system can reach such an efficiency. However, some could, in theory, approach this limit to within 10% which allows for pumping and stray thermal losses.

TOTAL SYSTEM PERFORMANCE

Given the degree of concentration, N, we estimate the net insolation to be .9N times the available insolation allowing for reflection and lens absorption, and thermal efficiency is assumed to be the $.9\eta_c$. The high temperature reservoir temperature is assumed to be the solar cell junction temperature. Air mass one conditions are assumed, and overall performance presented yielding an overall practitical efficiency of some 30% for the Si system and 36% for the GaAs system.

ECONOMICS AND PRACTICALITY

We are considering the use of solar cell-thermal systems as a part of the main power grid. As such the cost of energy produced must be competitive with conventional systems, both in a current cost sense ($ per kWhr cost to consumer), and in a capitol cost sense in $ per kWhr over the life of the equipment).

The solar system we are considering consists of subsections: (1) The land it is on; (2) The mechanical support structure including concentrating lens and tracking mechanisms; (3) The photovoltaic converters, and (4) The thermal system. Let us estimate the cost of a 10kW average system with a 20 year lifetime.

	(Si)	(GaAs)
$/kw	1,310	1,200

Conventional base load power plants vary in cost between $400 and $1000.00 depending on location and paper work so that these values are at least "in the ball park."

What about operating cost? Conventional plants require fuel, maintenance and supervision. These solar systems with fewer moving parts and no fuel requirements should cost less. Over 20 years the cost per KWh generated is estimated to be:

$kWh	.042 (Si)	.043 (GaAs)

The costs are less than typical costs of electric power in this country and indicate a significant probability that solar power will be competitive.

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A COMPARATIVE STUDY OF VARIOUS SURFACE BARRIER SOLAR CELLS ON POLYSILICON FOR TERRESTRIAL APPLICATIONS

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EXTENDED ABSTRACT

Of various alternatives, being presently investigated, for reducing by a large factor the cost of solar cells, surface barrier cells on polysilicon seem to be among the most promising. Surface barrier devices have a simpler structure and therefore require a less expensive processing. Use of polysilicon in place of single crystal silicon saves material cost. Unlike pn junction cells, the surface barrier devices do not have a dead layer at the surface, and are expected to have a better collection of photocarriers and therefore a higher short-circuit current density, on polysilicon substrates with small diffusion length.

A surface barrier can be realized on polysilicon in various ways. When the barrier layer is a semitransparent and ultrathin metal, one obtains either an MOS or an MIS cell depending on whether the interfacial layer is silicon oxide or some other insulator. When the barrier layer is a transparent and conducting semiconductor like the ITO (indium tin oxide), one obtains an SOS/SIS (semiconductor-oxide/insulator-semiconductor) cell. And, if the barrier layer is a liquid electrolyte (either aqueous or non-aqueous), one obtains a semiconductor-liquid junction, or in other words a photoelectrochemical cell.

The aim of the present work has been to fabricate the above types of surface barrier solar cells on cast polysilicon, obtained from Wacker Chemitronic, and determine their relative merits and demerits. The MOS cells were fabricated by growing the interfacial oxide (20 to 25 Å thick) in dry oxygen at 800°C and at 1.0 atmosphere pressure and subsequent vacuum evaporation of the semitransparent (40 to 70 Å) barrier metal (Au and Ag on n-type and Al on p-type). The SOS cells were fabricated by growing the interfacial oxide on p-type polysilicon in the same manner as above and subsequent ion beam sputtering of ITO in a mixture of argon and oxygen in the high vacuum system. The semiconductor-liquid junction cells were formed by simply immersing the polysilicon wafer in a number of liquid electrolytes and by using Au/Pt grid counter-electrode. For all the surface barrier cells, the back ohmic contact was gold on p-type and aluminum on n-type polysilicon.

To characterize the cells, current-voltage (I-V), diode current-voltage (I_D-V), and capacitance-voltage (C-V) characteristics were measured. The results obtained, so far, from these measurements and their analysis, can be summarized as follows: In case of MOS cells, the highest conversion efficiency obtained without any antireflection coating is 9.9% for a Ag on n-type polysilicon cell with an open-circuit voltage of 510 mV, a short-circuit current density of 27.0 mA/cm^2, and a fill-factor of 0.71. For the SOS cells, the highest conversion efficiency obtained without any ARC is 7.6% with an open-circuit voltage of 452 mV, a short-circuit current density of 24.7 mA/cm^2, and a fill factor of 0.68. In case of semiconductor-liquid junction cells made on polysilicon, instability and series resistance have been major problems. Open-circuit voltage as high as 780 mV has been obtained, however, short-circuit current density and fill factor are poor, and degrade rapidly with time.

THERMODYNAMIC METHOD FOR QUANTITATIVE TREATMENT OF CONDUCTION ELECTRONS

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EXTENDED ABSTRACT

INTRODUCTION

Two principal tools for the study of physical phenomena are: (1) mechanistic analyses; and (2) thermodynamics, the results of which are independent of any specific mechanism. Various disciplines differ in the extent to which these two tools are employed. Mechanical engineering uses primarily thermodynamics in the design of a steam turbine; physical chemistry relies about equally on quantum mechanics and thermodynamics for many research topics; physical electronics relies, at present, almost entirely on quantum mechanics (and statistical mechanics) for treatments of conduction electrons; for example, in photovoltaic devices. This paper will describe thermodynamic procedures for obtaining quantitative information on electrons (and holes), even in the chemically and structurally complex materials which are essential for solar-energy technology.

Conduction electrons have been treated as a thermodynamic component for more than one hundred years, and the concepts of chemical potential and electrochemical potential have been widely used for electrons for the past forty years. A good treatment is given in the book "Electronic Conduction in Solids" by Smith et al. [1]. The electrochemical potential of the electrons, $\bar{\mu}$, is the sum,

$$\bar{\mu} = \mu + qV \tag{1}$$

of the chemical potential,

$$\mu = \mu^{o} + kT\ell n\gamma N \tag{2}$$

and the electrical potential energy, qV, where q is the charge on the electronic carrier (electron or hole), V is the electrostatic potential, μ^{o} is a convenient reference value, N is the concentration of electrons and γ is an activity coefficient. Smith et al. have given an especially clear description of the relation,

$$\begin{matrix}\text{electromotive}\\ \text{force}\end{matrix} = \begin{matrix}\text{chemical}\\ \text{force}\end{matrix} + \begin{matrix}\text{electrical}\\ \text{field}\end{matrix} \tag{3}$$

in terms of the quantities in Eq. (1); namely,

$$\frac{1}{q}\frac{d\mu}{dx} = \frac{1}{q}\frac{d\mu}{dx} - E \qquad (4)$$

where the electrical field, E, is given by $E = -dV/dx$. However, because these authors base their treatment on electron theory, they are able to make little use of the power inherent in a full thermodynamic treatment. A detailed review of quantum-mechanical treatments of the electrochemical potential of electrons is included in the advanced monograph, "Chemistry of Imperfect Crystals" by Kröger [2].

METHOD FOR OBTAINING THERMODYNAMIC DATA FOR ELECTRONS

The thermodynamic method is based on the use of empirical data. A procedure for obtaining such data for conduction electrons was discovered by the author in the course of a study of quite a different phenomenon, thermomigration and electrotransport of carbon atoms within the crystal lattice of iron. The first step in the procedure is to make measurements to determine the energy of the electrons. The energy in question corresponds to the Fermi energy in present theory. As a specific example, consider a metal-metal couple, and for simplicity consider the special case of electron-conducting metals. The experimental data needed in this case are:

1. The contact potential between the two metals, V_c.

2. The absolute thermopower α of each of the metals.

Briefly, V_c determines a useful difference in chemical potential of the electrons in the two materials; the α values determine the thermodynamic activity coefficients in each of the metals.

The second step, a useful introduction of the electrochemical potential, depends on a separation of the electrical potential V into two parts, $V = V_g + V_e$. V_g is the potential generated by redistribution of electrons. A well-known example is the "potential barrier" that is generated at the junction of a metal-semiconductor diode (in the absence of any applied potential, V_a). Less well-known is the fact that a potential V_g also develops (and for basically the same reason, e.g., difference in chemical potential of the electrons) in a homogeneous conductor in a gradient of temperature. V_e is the local value of potential developed at a given point because of an applied (external) potential V_a. This division of V into V_g + V_e seems obvious and trivial, but in fact it is one of the keys to a successful application of the thermodynamic approach.

The final step (noting that Guggenheim's warning [3] applies for liquids, but Gibb's procedure [4] is appropriate for solids) is to split the electrochemical potential, $\bar{\mu} = \mu + qV$, into a chemical part, μ, and an electrical part, qV, Eqs. (1)-(4). Such splitting is essential for many applications, including the treatment of junctions, and is widely employed.

APPLICATIONS

The author completed the analysis described above in 1975 and then began to apply it to various phenomena involving conduction electrons. His first success was the treatment in 1977 of thermal conductivity in a semiconductor [5] for the simple case in which no flow of electronic carriers occurs. Data on PbTe were chosen for analysis because these data are usually incorrectly interpreted, the term involving the absolute thermopower being omitted. As a result, the addition of 10^{-3} mole fraction of PbI_2 appears to decrease the lattice component of the thermal conductivity by a factor of two. These erroneous data are then explained using special phonon mechanisms. When the data in question were correctly analyzed by equations derived by nonequilibrium thermodynamics, such a minute addition of PbI_2 was found to have an unobservably small effect on the lattice component.

The paper will discuss other applications of the thermodynamic method that have a bearing on the subject of alternative energy sources.

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FUNDAMENTAL MECHANISMS GOVERNING THE PERFORMANCE OF MOS-INVERSION LAYER SOLAR CELLS

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EXTENDED ABSTRACT

(I) INTRODUCTION:- The MOS-inversion layer solar cells have characteristically better performance than diffused-junction solar cells due to (a) the shallow-induced junction allowing high collection efficiency, attributed to large field existing in the inversion layer (b) being practically insensitive to surface recombination velocity and minority carrier lifetime of the n-inversion layer (c) the near ideal junction as compared to the diffused junction solar cells where damage occurs with the advance of diffused metallurgical junction. Thus both the space charge layer and diffused layer contain diffusion-induced crystal damage, escalating the forward component of the space-charge recombination current and reduce lifetime in the diffused layer, both lowering the collection efficiency. Inspite of the above mentioned advantages such solar cells are limited in their performance by various electronic, physical and technological parameters. This paper describes, phenomenologically, the mechanisms governing the optimum allowed efficiency of such solar cells and on the basis of detailed numerical calculations suggests the optimum design parameters and areas in which improvement can be expected in performance.

(II) FUNDAMENTAL MECHANISMS AFFECTING THE CONVERSION EFFICIENCY

II A. Fixed Oxide Charge, Q_{SS}:- Electrically active sites such as fixed oxide charge, Q_{SS} are formed in the oxide layers at or near the Si-SiO_2 interface (1) during the thermal oxidation of silicon. The formation of such electrically active sites occur in the region in which silicon is incompletely oxidised. The density of Q_{SS} after oxidation is significantly lower $\simeq 10^{12}/cm^2$ within the transition region. Control of fixed oxide charge (2) which is of technological importance remains largely empirical, inspite of several models proposed by several authors(3,4). These electrically active sites, being positive, image negative sheet of charge in the bulk semiconductor and hence cause inversion in the p-type semiconductor. If it is assumed that the density of these sites is spatially uniformly distributed, even at maximum technologically possible value of 2-3 X $10^{12}/cm^2$, these charges will be in no electrical communication with each other due to the limited spread of the wave-functions. Hence it is postulated that these sites occur in patches. To express this quantitatively the plane of the interface is conceptually divided into a number of characteristic areas. The collection of the photon-generated carriers in the active area of such cells depends on the electrical communication of these areas with the collecting grid. This poses a severe limitation on the efficiency of such solar cells as the sheet resistance of n-inversion region is very high ≈10KΩ/sq. as compared to diffused region having sheet resistance 50Ω/sq., affecting the series resistance and hence the fill factor. Experiments by Okamato(5), P.Van.Halen(6) suggest an optimum spacing between collecting grids to collect the carriers efficiently. However, such a collecting grid suffers from serious drawbacks being constrained by a) photolithographic b) shadowing to active area ratio limits. Detailed calculation considering the constraints offered by the photolithographic limits and shadowing to active area ratio yield an optimum spacing of 186μ between the collecting grids of width 14μ each.

II B. Oxidation / Processing Induced Nonlinearities

II B(1) Oxidation Induced Stacking Faults: The oxidation of the $Si \rightarrow SiO_2$ is usually incomplete, however, the degree of incommpleteness can be very small $\approx 10^{-3}$. The fraction of unoxidised silicon then becomes free atoms, severed from the lattice by the advancing $Si-SiO_2$ interface. Because of their high mobility in silicon lattice interstices, these atoms quickly enter the silicon interstices causing the lattice to be super-saturated with self-interstitials, which simultaneously undergo a surface regrowth process and if suitable nucleation sites are available, condense to form oxidation stacking fault(OSF). Such sites reduce device yield and perturb electrical characteristics dramatically. The most sensitive parameters are leakage current enhancing the diode reverse saturation current and lifetime of the carriers, both affecting the efficiency adversely. No quantitative results are available, though the generation rate of OSF expressed as $L = At^{0.8} \exp(-2.3eV/KT)$; L being the length of the stacking fault, t being the time of oxidation and A being the oxidation condition constant. However, qualitatively the interdependence of OSF with reduction in lifetime and increase in reverse saturation current are discussed on the basis of recombination.

II B(2) Surface States:- It has been proposed that dangling bond structural defects and impurities at the $Si-SiO_2$ interface contribute to the generation of interface states. These interface states have characteristics of charge storage centres and recombination-generation centres. These states do not perturb the device characteristics significantly due to heavily occupied states in the n-region allowing less recombination but however introduce second order non-linearities e.g. increase in reverse saturation current.

II B(3) Redistribution of Impurities:- Apparently the segregation coefficient of most impurities in the $Si-SiO_2$ system favours the impurities remaining in the silicon, yet without any external source, an oxidation step can increase or deplete the impurity near the surface and hence in principle it is possible to have p and n type impurity in the original slice by stacking up effect causing a localized junction; increasing the internal resistance of the cell and causing reduction in the open circuit voltage. A detailed calculation in the paper suggest the introduction of p -on the back surface.

III <u>TECHNOLOGICAL LIMITATIONS</u>:- The technologically optimum design calculations reveal low background doping ≈10Ωcm to ensure surface inversion, placing a limit on the maximum obtainable voltage factor and curve factor and oxide thickness ≈0.6μ to ensure minimum induced charge at the air-oxide interface, having detrimental effect on the optical transmittance. Optimum grid design to ensure low series resistance and to collect carrier efficiently suffers serious disadvantage of i) photolithographic and ii) shadowing to active area ratio limits.

IV <u>ELECTRONIC PARAMETER LIMITATIONS</u>:- Conventionally the efficiency of solar cells depends strongly on the electronic parameters characterising the transport-recombination and generation of electrons and holes in the solar cells, however MOS-inversion layer solar cells are insensitive to these parameters due to induced junction and low doping in the base region. Collection efficiency and I-V characteristics for specified conditions of temperature doping, carrier lifetime etc. are calculated in this paper. The effect of spatial inhomogenity in the semiconductor is also taken into account to characterise the deviations from the standard normal behaviour.

V <u>EARTH'S SURFACE OPERATION</u>:- Energy spectrum of sunlight on a bright sunny day on earth's surface at sea level is given by P.Moon(7). It also gives the maximum amount of energy utilized in the generation of electron-hole pairs in the semiconductor with different energy gaps. The band-gap characterises a cut-off in the sun's spectrum where there is a rapid decrease in the absorption coefficient, which means penetration of photons and eventually transmission through it. Also, photons having energy greater than the energy required to create an electron-hole pair will cause lattice vibration and less heating in the silicon lattice(8). Degradation in characteristics at elevated temperatures is analysed. Possibilities for improvement on technological limitations are discussed.

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DEVELOPMENT TRENDS FOR THE MASS PRODUCTION OF LOW COST CONDUCTOR-INSULATOR-SEMICONDUCTOR (CIS) SOLAR CELLS*

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EXTENDED ABSTRACT

Large-scale photovoltaic solar energy conversion systems will consist of many components other than the solar cell itself. The balance of the system (BOS) (e.g. energy storage, power conditioning etc.) also need further cost reductions, however at the present time a major obstacle to terrestrial application of photovoltaics is the high cost of solar cells. Possible cost reduction may emerge only from the technological breakthrough in the material and design aspect of solar cells. Both above options are incorporated in CIS solar cells and therefore offer one of the best prospects for cheap solar photovoltaic electricity [1]. The term CIS stands for conductor-insulator-semiconductor, and refers to a solar cell structure consisting of a base semiconductor covered by a very thin insulating layer (about 10-30Å, so that electrons can tunnel through it) and then a top conducting layer. The top layer must be transparent, to let light through to the semiconductor underneath, and should have low electrical resistivity, since it is an electrode. This top layer can be a metal film (Aℓ, Cr, Ti, etc.), an oxide-semiconductor (ZnO, SnO_2, ITO, etc.) or a combination of these leading to a wide variety of metal-insulator-semiconductor (MIS) [2] or semiconductor-insulator-semiconductor (SIS) [3] solar cells.

The key parameters in the optimization of CIS solar cells are the thickness of the interfacial layer and the work function of the top layer. The thickness of the interfacial layer should be less than the thickness at which photocurrent supression starts, but greater than the thickness for which the device behaves like a heterojunction or Schottky diode. The electrical characteristics of CIS solar cells are governed by the properties of the interfacial layer between the insulator and the base-semiconductor. In order to obtain optimum performance of these devices the base-semiconductor interface should be in strong inversion, which can be ensured by selecting the proper work function of the top layer. In the case of p-type CIS solar cells, the top layer work function should be less than or equal to the electron affinity of the base-semiconductor. For n-type CIS solar cells, the top layer work function should be greater or equal to the sum of the electron affinity and the band gap of the base-semiconductor [4].

From a fabrication point of view, the CIS structure is one of the simplest possible with a minimum of fabrication steps involved. The material considerations indicate that many low cost semiconductors could be used including solar grade, polycrystalline and amorphous semi-conductors both in the elemental and compound forms. In addition, highly developed MOS technology can be exploited in making low cost CIS solar cells [5]. Furthermore, the CIS solar cells have the following advantages over p-n

junction solar cells: (i) these devices can be processed at temperatures below 500°C giving longer minority carrier life times in completed devices; (ii) collecting junction located right at the surface of the base-semiconductor and eliminates a surface dead layer; (iii) elimination of heavy doping and band gap narrowing effects observed in diffused junctions [6].

There are two approaches that have been used in the fabrication of MIS solar cells, (a) transparent metal approach, and (b) grating approach. In case of transparent metal approach solar cells are fabricated from wafers polished on one side. Standard procedure for cleaning is used. After cleaning the wafer is placed in vacuum system (∿10^{-6} Torr) and the back contact (e.g. ∿5000Å for p-type devices) is deposited and the wafer is sintered to form a ohmic contact. The next step is to grow an ultra thin interfacial layer (∿10-20Å oxide) over to Si substrate. The deposition of ultra thin metal layer is followed by grid deposition and AR coating. In some cases the sheet resistivity of the metal layer is reduced by using a multimetal structure [7]. Another approach that can be used to reduce the sheet resistivity of ultra thin metal film is to use a combined transparent conducting layer approach [8].

In case of grating type MIS solar cell, the ohmic back contact and the interfacial layer are formed as in the transparent type device. After this the top contact is evaporated and its pattern defined by photolithography. The final step is the evaporation of the AR coating (e.g. SiO). The AR coating reduces the optical losses and induces an inversion layer at the surface of the base-semiconductor. Using this approach, 17.6% (AM1) efficient silicon MIS solar cells (active area = 3 cm^2) have been reported by Godfrey and Green [6].

The fabrication of SIS solar cells is basically the same as the transparent type MIS solar cells. The oxide-semiconductor is deposited by one of the following methods: CVD, evaporation, sputtering and ion beam coating method. In some cases the interfacial layer is formed by exposing the base semiconductor to an oxygen partial pressure in the vacuum chamber [9]. In another approach, the annealing process simultaneously reduces the sheet resistivity of the oxide-semiconductor and produces an interfacial layer [10].

In order to produce CIS solar cells on large scale, we have performed feasibility study based upon the SAMICS methodology developed at JPL. The details of an automated CIS solar cell factory will be presented. The facility is designed to maximize processing flexibility, control testing and to provide real time process and produce management. The conclusion of this work is that if solar grade silicon can be obtained for less than $10/kg and the CIS production is in the order of mega watts, the 1986 cost goal of $0.50 per peak watt (1975 dollar) can be very easily met. With 10% amorphous silicon CIS solar cells the large scale production would make photovoltaic electricity cost competitive now. Also, the cost of CIS solar cells is insensitive to relatively wide variations in conductor cost [11].

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THIN FILM PHOTOVOLTAIC SOLAR ENERGY CONVERSION

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EXTENDED ABSTRACT

INTRODUCTION

The major potential for thin film solar cells is in low cost (<50¢/watt) and simultaneous high efficiency (>10%). Best efficiencies reported for several thin film solar cell types are shown in Table I. Conversion efficiencies have not exceeded 9.1% for all-thin-film cells [1-4] (most are substantially below 9%), as contrasted to over 19% for single crystal silicon [5] and GaAs [6], and 10-15% for thin film on single crystal heterojunctions [7-11] and Schottky devices [12].

TABLE I. EXPERIMENTAL SOLAR CELLS EMPLOYING THIN FILMS

ALL THIN FILM	REPORTED EFFICIENCY	REFERENCE
Cu_2S/CdS	9.1%	1
InP/CdS	5.7%	2
$CuInSe_2$/CdS	6.6%	3
Cu_2S/(Zn,Cd)S	7.8%	4
HYBRID		
InP/CdS	15.0%	2, 7
$CuInSe_2$/CdS	12.5%	8
CdTe/CdS	10.5%	9
InP/ITO	14.4%	10
Si/ITO	12.0%	11
GaAs/Au	15.0%	12

The purpose for fabricating hybrid cells (thin film on single crystal) is to establish the feasibility and limiting efficiency for a potential solar cell material. Interesting examples seen in Table I are InP and $CuInSe_2$ (both p-type, with CdS as the n-type collector). Comparing the hybrid and thin film versions of these cells, we see that the efficiency drops quite drastically for the thin film version, due to grain boundary recombination and other effects.

$Cu_2S/Zn_xCd_{1-x}S$ THIN FILM CELLS

The Cu_2S/CdS thin film cell is the most thoroughly investigated and most efficient of all thin film cells, and has been reviewed in several places [13-15]. The (Zn,Cd)s alloy for use as the n-type collector is being investigated because it offers potentially about 50% more voltage than is available from the Cu_2S/CdS cell. Higher V_{oc} values for $Cu_2S/Zn_xCd_{1-x}S$ cells have been reported from several sources [16-18]. However, current densities are lower than for Cu_2S/CdS cells made under similar conditions. This anomalous (not expected from the model) decrease in J_{sc} can be potentially attributed to poor Cu_2S (non-stoichiometric, zinc impurities, etc.), to changes of the base material (lower mobility and electric field in the $Zn_xCd_{1-x}S$), and to properties of the interface.

We have verified using several analytical techniques that a major problem with the $Cu_2S/Zn_xCd_{1-x}S$ junction relates to the ion-exchange reaction by which this junction (and also Cu_2S/CdS) is typically formed. Auger/ESCA measurements have verified that there is an anomalous excess of zinc near the junction region. Chemical profiling has been performed using Auger/ESCA and atomic absorption spectroscopy, verifying that a zinc rich layer (atomic Zn/Cd ratios greater than 3 in some cases, whereas this ratio should be $\lesssim 0.3$) exists within about 0.2μm of the interface. Additional studies using the electron beam microprobe to determine the lateral (parallel to the junction) zinc distribution are also being carried out. The above measurements have also verified that there are not major amounts of Cd and Zn retained in the Cu_2S (concentrations measured via AAS are less than about $10^{19}/cm^3$).

MODIFIED $Cu_2S/Zn_xCd_{1-x}S$ JUNCTION MODEL

The $Cu_2S/Zn_xCd_{1-x}S$ junction model has been basically that of the Cu_2S/CdS, modified for the change in the $Zn_xCd_{1-x}S$ band parameters [19]. It has been assumed that the presence of Zn in the base layer does not significantly alter the expected chemical composition near the junction. Our results indicate that major changes should be made in the $Cu_2S/Zn_xCd_{1-x}S$ band diagram if that junction is formed by ion-exchange. We present such a model, with a potential spike that is not laterally uniform across the junction. This results from the accumulated Zn under the interface, which itself is due to a non-isotropic ion exchange. That is, the reaction rate is a function of crystalline direction, and should result in laterally non-homogeneous Zn pileup under the interface. This model can account for both the V_{oc} increase and J_{sc} decrease measured for $Cu_2S/Zn_xCd_{1-x}S$ solar cells.

RECOMMENDATIONS

These studies indicate that experimental $Cu_2S/Zn_xCd_{1-x}S$ cells, with the Cu_2S formed by other techniques (evaporation, sputtering, chemically) should proceed. If the sub-interface Zn rich layer can be precluded, then the higher open circuit voltages along with currents comparable to those of the Cu_2S/CdS should be possible, as should conversion efficiencies in the vecinity of 12%.

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DESIGN OF A 100KW PHOTOVOLTAIC FLAT PANEL SYSTEM AT A WASHINGTON, D.C. AREA WASTE TREATMENT PLANT

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EXTENDED ABSTRACT

INTRODUCTION

The BDM Corporation, with its subcontractors, has designed a 100 Kilowatt flat panel photovoltaic system to supply power to a large industrial load at the Washington Suburban Sanitary Commission (WSSC) waste treatment plant at Piscataway, Maryland [Reference 1]. Team members included Inter-Technology/Solar Corporation (ITC); Optical Coating Laboratories, Incorporated (OCLI); Windworks, Incorporated (WWI); WSSC; Southern Maryland Electric Cooperative (SMEC) and ARCO Solar, Incorporated (ASI).

SYSTEM OVERVIEW

The PV system consists of five major elements. These are (1) PV cells and modules, (2) a power conditioning system, (3) isolation transformers, (4) instrumentation and control system, and (5) a power distribution system.

The PV array consist of over one thousand PV modules forming a 0.6 acre array field that generates approximately 100 kilowatts of energy during normal operation on a full sun day.

The power conditioning system consists of a line-commutated inverter, isolation transformers and solid-state switching control circuitry. The system, operating at 94-96 percent efficiency, controls the distribution of power to the dewatering facility and/or other plant loads depending upon the load demand and array output on a particular day.

The inverter is operated in a maximum power tracking mode whereby the internal inverter circuitry senses the maximum power point of the array current-voltage characteristics and "tracks" the locus of these points, as they vary due to changes in operating temperature or insolation levels. Thus the array output power is automatically maximized for a given set of operating conditions.

Instrumentation for system evaluation and control is designed to maintain independent functions. Performance data for system evaluation is obtained with an on-site data acquisition system (ODAS). The array, the load, and the inverter are protected against overload conditions by isolation transformers and appropriate breakers in switch panels.

CONCEPTUAL SYSTEM DESIGN

Two basic operating modes are designed for the subsystems of the PV array. These involve programming of the inverter to operate in a static programmable (linear) mode or in a maximum power tracking (non-linear) mode.

The 100KW array is configured in rows of interconnected modules. The size of an individual row was determined by the system DC operating voltage of 530 volts. By making an individual row operating voltage identical with the system DC voltage, costs could be reduced by eliminating inter-row series connections. All of the power produced by a row is carried in a single bus at the back of the row to a single conduit buried along one edge of the row to reduce interconnect costs.

Three inch and four inch diameter circular cells were chosen respectively by OCLI and ASI since they are compatible with crystal growth practices, waste less silicon than rectangular cells, and facilitate the production process.

The differences between the OCLI module and the ASI module, in addition to physical size, cell interconnections and cost, include: (1) high cell efficiency versus industry-average efficiency, (2) hand assembly versus a mass production process, (3) 11 percent power loss versus total power loss for a single cell open-circuit, (4) 90 watts versus 37 watts.

PERFORMANCE ANALYSIS

Load Satisfaction Table 1 summarizes load satisfaction calculations. It is important to note that a significant feature of the system is that power delivered to the load is available to the rest of the plant when the dewatering apparatus is shut down. This results in a 100 percent utilization of the power delivered by the system and, in itself, negates any requirement for battery storage.

TABLE 1. LOAD SATISFICATION

MANUFACTURER	OCLI	ASI
ARRAY SIZE (NOMINAL)	100KW	100KW
INVERTER OUTPUT TO PRIMARY LOAD	65MWH/YR	70MWH/YR
PRIMARY LOAD	285MWH/YR	285MWH/YR
PRIMARY LOAD SATISFIED	23%	25%
ARRAY EFFICIENCY (OUTPUT/INSOLATION)	12.8%	9.9%

Levelized Busbar Energy Costs A computer analysis produced levelized bus-bar energy cost for a privately-owned utility and cost parameters that reflect WSSC ownership (publicly owned, non-profit, etc.). [References 2 and 3]. Results are summarized in Table 2.

TABLE 2. LEVELIZED BUSBAR ENERGY COSTS		
MANUFACTURER	OCLI	ASI
ARRAY SIZE (NOMINAL)	100KW	100KW
UTILITY OWNERSHIP	$0.70/KWH	$0.50/KWH
WSSC OWNERSHIP	$0.45/KWH	$0.30/KWH

KEY ISSUES

High Efficiency Cell Versus Low Efficiency Cell The rationale for using a high efficiency cell is twofold; (1) high efficiency reduces spatial area required by the array and (2) costs other than cell costs will be the major portion of future system costs. In a developmental and experimental PV system, it is beneficial to use state-of-the-art components that show a high probability of future availability. Future cell costs will decrease as a result of automation and other expected technology advances. Other costs, such as real estate, construction, etc., are increasing and will become system cost drivers as cell costs decrease.

Production Risk The ASI cell reduces the technical risk of constructing this system to essentially zero. Inherent in the OCLI cell/module design is a higher technical risk but also the promise of having a state-of-the-art array.

Module Reliability/Cost The OCLI parallel interconnect scheme currently requires manual processes to fabricate. Extra costs are realized for the high technology, higher reliability that this module design incorporates.

The ASI series connected module is mass produced using a highly automated process. Lower costs are realized for the mass produced, lower reliability that this module design incorporates.

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UNDOPED a-Si PHOTO VOLTAGE VARIABLE RESISTOR

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EXTENDED ABSTRACT

INTRODUCTION

The I-V characteristics of undoped a-Si photoconductors are studied in this work. Undoped a-Si films were deposited from a glow discharge plasma of silane and helium using a horizontal glow discharge deposition apparatus [1,2]. SiO_2 and stainless steel substrates were used at a growth temperature of 270°C. The operating pressure of silane-helium mixture was 0.3 Torr. A heavily doped top layer was formed a few hundred Angstroms thick by using 1 1/2% phosphine, 10% He added to silane. Contacts to top surface in the form of line strips were made by evaporating gold for both SiO_2 and stainless steel substrates.

RESULTS AND CONCLUSIONS

The ratio of the photoconductive response to dark current was greatest at the starting condition of 23°C. The I-V characteristics were non-ohmic. The non-ohmicity increased considerably under light.

When the temperature was increased both the dark current and the currents increased but the ratio between them dropped considerably. Such a ratio was found to be independent of the bias voltage. When samples were heated to 300°C and cooled back to 23°C, the dark currents were reduced by a factor of two. The ratio of the photo to dark currents was the same, however. This means that heating to 300°C had an irreversible effect on the dark resistance of the samples possibly due to microcracks. The intensity dependence of the photoconductive response follows the relation P^γ where P is the incident power and $\gamma = 0.72 \pm 0.03$. This indicates that the recombination mechanism involves a distribution of states in the band gap and cannot be represented by a simple one or two level mechanism.

It is also interesting to observe that since the ratio of photo to dark currents can be retrieved after heating to 300°C, the temperature endurance capability of this photoconductor is very substantial. It appears that this device can be used as a sensitive voltage variable resistor if exposed to light at room temperature. This is particularly interesting for automatic gain control and related feedback problems.

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P/UNDOPED a-Si PHOTODIODE AND DIODE-VOLTAGE VARIABLE RESISTOR COMBINATION

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EXTENDED ABSTRACT

INTRODUCTION

Interest in a-Si solar cells has been increasing [1-3]. Glow discharge seems to be particularly interesting since films deposited herewith exhibit a lower density of states in the gap [4]. In this work we intend to study the basic properties of p/undoped a-Si junction and its potential beside solar cell. Glow discharge technique was used. Chromium coated SiO_2 substrates were placed on graphite susceptor inside a reaction tube. A few hundred Angstroms bottom layer of n+ Si was formed by using 1 1/2% phosphine, 10% He in silane 1 μm thick undoped a-Si film was then deposited by the decomposition of silane at 0.3 Torr. The growth temperature was around 270°C. The p region was formed by using 500 ppm deborane in He mixed with silane in the ratio one to one. Contacts in the form of dots were made by evaporating gold. Etched chromium provided the back contact.

RESULTS AND CONCLUSIONS

The forward current of this device was found to deviate markedly from the simple exponential dependence $I_O\ e^{V/mV_T}$, where I_O is the saturation current and V_T is the thermal voltage. If such a relation is used m varies from 40 to 160 for current variation from 2-14 μA. This indicates that the rectification characteristic of this device is not identical with that of known p-n diodes.

Moreover, it was found that under reverse bias I_O was not constant but increased more or less quadratically with the reverse voltage. At best, this device can be thought of as an ideal pn diode in series with a non ohmic light dependent voltage variable resistor. At forward bias, the series resistance prevails, while at reverse bias conduction is determined by this quadratic voltage dependence.

As a solar cell, the FF was found to be 0.42. The intensity dependence of the short circuit photocurrent was found to be

$P^{0.72\pm.03}$ where P is the incident power.

This device can be used as a photodetector, and as DI-VVR (voltage variable resistor-diode combination). The non-ohmicity in the IV characteristic can extend to several volts (asymmetry has been recorded up to ± 30 V dc bias voltage). This feature may be particularly attractive in the manufacture of function generators as a replacement of piecewise networks.

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SESSION 2C

NUCLEAR ENERGY II

OVERVIEW OF NONELECTRICAL APPLICATIONS OF FUSION ENERGY

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Since fusion energy represents one of the most attractive inexhaustible energy sources, it is important to consider how well fusion can satisfy non-electrical as well as electrical energy needs. Indeed, three unique characteristics might be exploited [1]: 1) neutrons from D-T and D-D fusion can be used to induce nuclear reactions, 2) the natural separation of the reaction zone and heat deposition region enhances the feasibility of high-temperature blanket processing, and 3) an intense source of both radiation and high-temperature plasma is inherently available.

Interestingly, the original interest in fusion in the early 1950's viewed it as a neutron source for fissile fuel production. The hybrid approach [1-3] is now considered as a possible near-term application of fusion since it would fill an immediate need (fuel for light water fission reactors, LWRs) and, by alleviating plasma requirements, make a fusion application possible earlier. The attractiveness of this approach rests on questions ranging from the future of LWRs to the speed that a practical hybrid system can be developed and its relative economics.

In contrast to hybrids, other nonelectrical applications are not generally thought of as a route to early development of fusion. If anything, the added complexity of such systems seems to relegate them a development status that would follow commercialization of electrical power stations. The potential for such applications are still of immediate concern, however. The choice of a future energy source may well revolve around its flexibility and ability to meet a variety of needs. Consequently, our support for the large R&D costs for fusion could depend on how strong the conviction is that nonelectrical uses are possible.

The first serious proposal to exploit other applications was the suggestion of a "fusion torch" (FT) for material's processing and recycling.[1] The FT would utilize the large energy density of the fusion plasma to vaporize injected materials with subsequent separation into constituent species. Promotion of chemical reactions with the FT was also considered. While the FT retains a long-term attractiveness, most attention in recent years has turned to less complex concepts generally involving high-temperature blankets in one form or another [4,5]. Examples receiving preliminary study include: hydrogen production via either high-temperature electrolysis or thermochemical cycles; production of synthetic natural gas (SNG) and/or liquid fuels from coal; high temperature chemical production such as nitrogen fixation or decomposition of CO_2; and general process heat production. While various reactions driven either by radiation or by neutrons have been considered [1,6], these are considered quite speculative (relative to finding efficient, high yield reactions of economic interest) compared to the high-temperature blanket approach. Thus, for example, LASL studies consider a bismuth-sulfate thermochemical cycle for H_2 production while BNL workers have examined high-temperature electrolysis [4,5]. These and related studies at GA, ANL, MSNW, and PSE&G [4,5] have confirmed the potential attractiveness of such approaches, but have identified unresolved problems including: the competitiveness of costs remains uncertain; materials problems require further definition, possibly being the "achilles heel" of such approaches; requirements for simultaneous generation of tritium may compromise system performance, suggesting investigation of D-D fueled approaches. Attractive features identified include: the generation of heat at temperatures above those feasible in a fission blanket; the potential to supplement plant operation, e.g., reverse operation of H_2 electrolytic units could produce restart energy and also a spinning reserve; a potentially easier route for commercialization of fusion power, e.g., H_2 production could extend gas supplies and provide a smooth transition utilizing current methane-based transmission/ distribution systems. In conclusion, nonelectrical applications appear destined to play a major role in fusion development and commercialization.

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Dup

REALISTIC ASSESSMENT OF DIRECT RADIOLYSIS FOR SYNTHETIC FUELS PRODUCTION USING FUSION RADIATION SOURCES

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EXTENDED ABSTRACT

The use of fission reactor radiations, including neutrons and gamma photons, but with emphasis on fission fragments which carry off ~ 80% of fission energy release, has been extensively investigated for direct radiolytic production of large volume chemicals. Potential products include synthetic fuels by water or carbon dioxide decomposition, fixed nitrogen from air, and ozone from oxygen. Interest in fission reactor radiolysis has largely vanished because of apparently insurmountable obstacles to simultaneous economical achievement of high efficiency in conversion of radiant energy to stored chemical energy of radiolysis products and acceptable levels of product radioactivity contamination. More recently, the use of fusion reactor radiations for direct radiolysis has been of interest. Fusion reactor radiations are apparently more suitable for radiolytic chemical production, but many obstacles to commercialization using fission radiation sources must also be faced with fusion sources, albeit to a lesser degree.

Because the conditions required for useful thermonuclear energy release are less extreme for deuterium-tritium (DT) fusion than for all other fusion reactions, at least the first few generations of fusion reactors are expected to burn deuterium and tritium. Up to ~ 80% of primary DT fusion energy release is represented by 14-MeV neutron kinetic energy, with the remainder carried off by x-ray photons and energetic ions. Further fusion reactor energy release results from exoergic reactions of fusion neutrons with reactor blanket, coolant, and structural materials. The highly penetrating nature of fusion neutrons permits utilization of a majority of fusion reactor energy release in blankets surrounding reactor cavities independent of cavity phenomenology. However, these highly penetrating neutrons also present problems. Many radiolysis reactions are conducted most efficiently in the gas phase, but gases have such small stopping powers for high-energy neutrons that either very thick blankets or high pressures, which generally reduce radiolysis efficiencies and impose undesirable reactor structural requirements, will be required to provide adequate neutron energy absorption. Tritium breeding in lithium-containing blankets surrounding fusion reactor cavities sufficient, or nearly sufficient, to close the tritium fuel cycle may be necessary for economic viability. Simultaneous tritium breeding, prevention of product contamination with tritium and other radioactive species

produced by neutron interactions with the radiolysis mixture and reactor structure, and use of a high percentage of total fusion reactor energy release for radiolysis appears to represent an extraordinarily difficult engineering problem with no apparent solutions in sight.

Radiolysis efficiency for a particular radiation and a particular radiolysis product can be expressed in terms of a G value, defined as the number of molecules of that product produced per 100 eV of radiant energy deposited in the reaction mixture. The ratio of experimental G values to maximum G values for endothermic reactions, corresponding to complete utilization of radiant energy, gives the efficiency of radiant energy utilization. Among the highest G values reported for H_2O decomposition to give H_2 and O_2, CO_2 decomposition to given CO and O_2, and HCl decomposition to give H_2 and Cl_2 are $\sim$15, $\sim$10, and $\sim$8 respectively. The corresponding maximum G values are 40.3, 34.5, and 101.2, which result in respective radiolysis efficiencies of $\sim$37%, $\sim$29%, and $\sim$8%. This suggests that only topping cycle applications or combined radiolytic-thermochemical cycle applications, for which HCl radiolysis has been proposed, can be economically viable. If this is the case, then thermal energy rejected from such cycles must be available at temperatures high enough to permit efficient further utilization.

Significant influences on the efficiencies of radiolytic processes include (1) type of radiation, (2) radiation intensity or dose rate, (3) temperature and pressure, (4) radiolysis product concentrations, and (5) whether or not back reactions are inhibited by phenomena that separate excited reaction products until they are deactivated, by continuous removal of reaction products from the reaction mixture, or by prompt deactivation of reaction products with so-called scavengers. Some of these promote radiolytic production of desired substances, but others hinder their production. The listed G values were obtained under conditions that favor the desired radiolytic reactions, but which may also involve, (because radiolytic processes are still only imperfectly understood) hidden factors that hinder radiolysis and which if eliminated or counteracted might lead to higher G values.

The first influence is generally characterized in terms of the linear energy transfer or LET, the mean energy deposition density along a radiation track. Heavy charged particles have large LET values, e.g., $\sim$ 3 to 25 eV/A for alpha particles of various energies and fission fragments (mean), whereas gamma and x-ray photons, beta particles, accelerated deuterons and neutrons exhibit small LET values, e.g., $\sim$0.02 to 1.0 ev/A. For many radiolysis reactions, radiolytic efficiency increases with increase in LET value. Fusion neutrons interact with radiolysis mixtures and transfer energy in a variety of ways to readily convert neutron energy to a mixture primarily of high LET charged particle kinetic energy and low LET gamma photons. Considerable experimental evidence suggests that very-high-dose-rate, pulsed irradiation, characteristic of inertial confinement fusion can give substantially higher G values than does steady irradiation, characteristic of magnetic confinement fusion, for the same time-averaged radiation fluxes. Although there are some apparent exceptions, G values generally decrease with increase in gaseous radiolysis mixture pressure, probably because of increased back reaction rates, but higher densities result in thinner blankets for gaseous radiolysis mixtures. Higher temperatures can result in higher G values for at least some radiolysis reactions. For example, G values for water vapor radiolysis jump sharply at about 250°C. However, theory suggests that it is a one-time effect only and that further increases in temperature will not lead to further sharp jumps. The highest G values are obtained when radiolysis product concentrations are low, corresponding to low back reaction rates. Back reactions can also be stimulated by radiation, so that steady state concentrations are often largely determined by the type and intensity of the radiation, rather than by ordinary thermodynamic considerations. On the other hand, low product concentrations can mean increased recycle of reactants and expensive product separations. Scavengers, such as HCl and HBr, that are simple, readily-reconstituted (required because of radiolysis of scavengers themselves), inorganic compounds substantially increase G values for hydrogen production by water radiolysis. Scavengers were used to obtain the listed maximum G values, but more effective scavengers may exist. Disproportionation of H_2 and O_2 between phases in liquid water-steam mixtures reportedly enhances G values for H_2 production by separation of radiolysis products, but the enhancement may be solely a result of the temperature effect previously discussed. On the other hand, a similar effect may be useful with other radiolysis systems. There is experimental evidence that inhibition of diffusion of dissociation products that occurs in critical regions due to vanishing of chemical potential driving forces for diffusion at critical points can significantly reduce rates of recombination of radiolysis products. Unfortunately, critical temperatures for many radiolysis systems of interest are rather low and efficient utilization of reject heat is thus precluded. Nonetheless, attractive radiolysis systems with higher critical points may be discovered. A principal reason for low G values for many radiolysis processes is that much of the radiant energy is transformed into molecular excitation energy short of that necessary to cause dissociation. Lasers could be used to selectively and efficiently introduce into the excited species the small additional amounts of energy required for dissociation.

Our, and other studies, of the economics of synthetic-fuel production by direct radiolysis, all of which ignore some of the technology problems, suggest that direct radiolysis cannot compete with other methods of synthetic-fuel production, including coal gasification and liquifaction, production of synthetic crude from tar sands and oil shales, and fusion-driven thermochemical and electrolytic hydrogen production. Principal barriers to commercialization of radiolytic processes include low G values and radioactivity contamination of products.

LASER FUSION SYSTEMS FOR PROCESS HEAT

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EXTENDED ABSTRACT

The decrease in the supply of petroleum and natural gas as sources of energy for industrial processes has led to the investigation of inertial confinement fusion systems for process heat applications. Battelle-Columbus began a study of laser fusion process heat systems in 1977. Three objectives of the study were (1) to determine industrial process heat requirements, (2) to determine the criteria used by industry in the selection of a heat source, and (3) to conceptually design a laser fusion process heat system to meet the needs and the criteria of industry.

Based on an analysis of industry process heat requirements, five basic plant sizes and process heat temperature ranges were selected. Table 1 shows the five design points selected and the industry to which the system would be applicable. These five design points were used to conceptually design five laser fusion process heat systems.

TABLE 1. POTENTIAL POINT DESIGNS--LASER FUSION PROCESS HEAT SYSTEMS

Application	Size, MW	Temperature Range, F
Steelmaking	3000	2600 - 2700
Inorganic chemicals Pulp and paper	300	1500 - 1600
Petroleum refining	500	1000 - 1100
Petroleum refining	500	800 - 900
Many	500	350 - 650 Steam

The basic design includes a gas laser system, a power module with a blanket capable of converting the fusion neutron energy into heat energy at the specified temperature, a heat exchanger system capable of separating the blanket heat transfer fluid from the fluid used to transfer the heat to the process, and an electrical generating system capable of supplying the power required to operate the laser and other plant systems. The major differences between the five systems, other than component size, are the blanket neutron energy absorbing material and the blanket heat transfer fluid.

The blanket designs for the five systems include a water blanket, a liquid lithium blanket, a sodium cooled graphite blanket, and helium cooled aluminum oxide and graphite pebble bed blankets. In developing blanket designs, the assumption was made that tritium would be available for purchase from fusion power stations which are breeding excess tritium.

The industrial criteria for the selection of an energy source were divided into four issue areas. These were technological, economic, institutional, and environmental and safety considerations. The criteria were determined and prioritized by several groups of industrial experts, including the research sponsors.

These selection criteria were used as input to the system design process. Some of these impacts are shown by the following examples. The system supplying energy to the industrial process is required to have a high availability. The availability requirement meant that the system had to be designed with a large number of internal redundant and/or standby components. The principal factor considered by industry in the selection of an energy source is cost. The method used for calculating the costs and the return on investment required are very different than the costing methods used by utilities. This led to the development of a cost model based on the industrial requirement.

Several conclusions have been reached as a result of this study. The examination of industrial process heat requirements has shown that not only is there a large requirement for process heat but also based on today's plant sizes, large process heat sources of 300 - 3000 MW are not unreasonable. However the use of large centrally located process heat producing systems may require major redesign of process plant layout and equipment.

The requirement that the availability of the process heat system not determine the availability of the process can be designed into the process heat system by use of redundant and standby components. The primary impact of the redundancy is in the cost associated with the components and the increased complexity required to switch from one component to another while the plant is in operation. Provision must also be made to repair failed components in the radioactive environment of the operating system.

A review of alternative energy sources for industry indicates that in order to be in the competitive range, a laser fusion process heat system would have to produce energy at less than approximately \$8 per 10^6 Btu. It should be recognized that cost estimates based on conceptual designs and extrapolations of technology are very unreliable. The objective of the crude cost analyses performed in this program was to evaluate whether the laser fusion system would be clearly competitive or clearly noncompetitive. For the assumptions made, the crossover point into the competitive region was at 500 MW. For a plant size of 1000 MW the estimated cost was \$7 per 10^6 Btu and at 3000 MW it was \$5.5 per 10^6 Btu. Considering the associated uncertainties, it can only be said that with certain technological development a laser fusion system could be made economically competitive.

The development of lower cost drivers and more highly radiation resistant materials could lead to substantial economic benefits. The laser systems make up 30 - 60 percent of the system cost depending on the total system size. Also the higher power systems with simple dry first wall designs require large reactor chambers and associated equipment and facilities. Since the second largest portion of the cost is associated with these systems, any significant reduction in size could lead to a substantial cost savings.

FUSION DRIVEN FISSILE FUEL BREEDER SYSTEMS

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EXTENDED ABSTRACT

The current generation of light water fission reactors (LWR) is inefficient in its use of nuclear fuels because only about 1% of the overall uranium feed is fissioned to create electricity. Although improvements in fuel utilization can add an additional 0.5-1% via advanced fuel and reactor designs, it has long been recognized that there are two necessary ingredients required to fully utilize our fertile reserves of uranium and thorium. The first, fuel reprocessing is required to extract useful unburned fuel constituents from spent reactor fuels. The second, breeder reactors, which can convert more fertile fuel (i.e., ^{238}U or ^{232}Th) into fissile fuel (i.e., ^{239}Pu or ^{233}U) than burned in creating fission power, are also required.

The technologies for both fuel reprocessing and breeder reactors have been developed in several countries and are now commercially available - most notably in France. In the United States current policy is to defer commercial fuel reprocessing and the demonstration of liquid metal fast breeder reactor (LMFBR) technology until issues concerning the proliferation of nuclear weapons materials are resolved. In addition, in this country, it now appears that these technologies might not be required commercially until after the year 2000.

Considering this perspective there exists a strong possibility that a breeder with characteristics which are superior to those of the LMFBR can be developed in the same time frame. This breeder, the fusion breeder or fusion-fission hybrid reactor, is based upon the use of neutrons produced in the D-T fusion reaction. These neutrons, when absorbed by fertile fuel in the blanket region of a fusion reactor, can lead to either fast fissions or fissile fuel production. The former can serve as a power amplifier for the fusion device - most useful for the first generation of fusion reactors, while the fissile fuel which is produced can be used to fuel existing LWRs. Relative to the LMFBR, fusion breeders have the following potential advantages:

- much greater excess fuel production per plant

- more flexible fuel cycle options for proliferation resistance
- the bulk of the electricity generation system (i.e., breeder plus fission burners) can be current state-of-the-art technology LWRs - safety and institutional advantages
- faster commercial deployment and larger energy production impact after introduction
- competitive system electricity cost with better cost stability

Although the fusion-fission hybrid option was first recognized over 25 years ago, recent progress in fusion research (probable tokamak energy breakeven in 1983) has motivated considerable work in this area because it is considered to be a "near-term" application of fusion. As a result, evolution of the fusion breeder reactor concept has progressed during the past four years from early neutronics scoping calculations through detailed conceptual power plant designs based upon the tokamak, mirror, and inertial confinement concepts. These designs include thermal hydraulic, structural, fuel cycle, subsystems, and costing considerations. The results of engineering design studies have been helpful in resolving a number of issues concerning the attractiveness and feasibility of fusion breeder technology. To begin, results of earlier neutronics scoping studies have been confirmed at a higher level of engineering detail. Also, much of the required blanket and power plant technology can be straightforward extension of previously developed fission reactor technologies. In addition, it appears that hybrid technology does not necessarily incorporate the worst features of both fusion and fission technologies, but can in some respects represent a considerable relaxation of the difficulties associated with each. For example, hybrids can operate with a fusion gain of 2-3 - less than 1/3 of the gain required for pure fusion systems. Also, the hybrid blanket fission power density and fuel burnup can be substantially less than corresponding quantities for an LMFBR.

In general, results we will discuss indicate that a fusion breeder which costs 3 times as much as a current LWR nuclear power plant (per unit thermal power) can supply fissile fuel for 15-40 (equivalent thermal power) fission reactors. In such cases the overall cost of system electricity is less than 20% higher than current nuclear power costs. In addition, our deployment studies indicate that fusion breeders fueling fission power reactors can have a major impact on energy supply (perhaps accounting for 30% of our total electricity demand) within 20 years after possible commercialization in 2010.

In our presentation we will present recent designs for fusion breeders based upon the tokamak, mirror, and inertial confinement schemes. Generic features of each which bear upon hybrid performance will be discussed. In addition to engineering design studies for fusion breeders we will present results relating to technology and materials development, symbiotic electricity generation systems performance and economics, fusion breeder deployment scenarios, and the effects of uncertainties in breeder cost and performance.

CONCEPT EVALUATION OF NUCLEAR FUSION DRIVEN SYMBIOTIC ENERGY SYSTEMS

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EXTENDED ABSTRACT

Continued use of present-day LWRs operating on the stowaway uranium fuel cycle would lead to limited use of nuclear energy from a long-term viewpoint. In addition, the nuclear policy statement by President Carter on April 7, 1977, has led to an emphasis on alternate energy sources not involving access to materials directly useful for weapons production. The need to minimize the proliferation of sensitive facilities, while extending fuel resource utilization, have spurred renewed interest in symbiotic systems and denatured (less than 12 w% U-233 in U) fuel cycles.
In symbiotic energy systems, fissile material is bred in drivers (e.g. nuclear fusion or nuclear fission breeders) and is used in burners (e.g. advanced converter nuclear reactors). In the drivers, two fissile materials can be bred : fissile-plutonium from U-238 and U-233 from thorium. The breeding of fissile-plutonium is avoided because it cannot be denatured. In addition, for metallic fuel, thorium metal alloys exhibit more desirable metallurgical properties than uranium.

In this paper we present detailed neutronic and economic analyses, as well as technology requirements, of several symbiotic energy systems.
Neutronic calculations are presented for CTR (Controlled Thermonuclear Reactor) blanket configurations that attempt to maximize fuel (U-233) production and minimize power production within the blanket. This approach is taken because :

1. Optimization of a symbiotic system , with the goal of minimizing the overall power cost, implies minimization of the driver blanket multiplication[1].
2. Low blanket energy multiplication decreases the maximum power density and the temperature swings of the fertile fuel elements in the blanket.
3. Large amounts of weapon-grade fissile material can be generated by a pure nuclear fusion power system or by a nuclear driver. Therefore we wish to maximize the number of proliferation-proof burners (e.g. denatured U-233 reactors) per driver.

The neutronic calculations for the CTR blanket (surrounding D-T or semi-catalyzed D-D fusioning plasmas) are performed with a revised version of the discrete ordinates code XSDRNPM[2], which incorporates a fuel depletion option. The DLC-37 multigroup coupled cross-section library[3] was used.

The use of coupled CTR systems, in which some CTRs are devoted to U-233 production and others are devoted exclusively to tritium production, are explored for blankets surrounding D-T plasmas. Also, the use of Pb-Li alloys to maximize tritium production is studied. With these designs, excellent U-233 breeding characteristics are achieved. The use of the endothermic (n,2n) reaction in Pb, to increase the ratio of neutron to energy multiplication in the blanket, is explored. Metallic thorium and $NaF\text{-}BeF_2\text{-}ThF_4$ salt blankets were analyzed. The maximum power density in the thorium metal pebbles of the fusion blanket varies typically from 135 watts/cc at begin-of-cycle (BOC) to 325 watts/cc at end-of-cycle (EOC) for 1 Gwe fusion drivers which we studied. No reactivity control equipment is needed since typically keff=0.43 at EOC. Also, the performance of the symbiotic system is very dependent on the maximum power density allowed in the blanket and on the shape of the plasma burn.

The nuclear fission breeder, used as a driver in this study, has parameters characteristic of heterogeneous, oxide LMFBRs[5]. This breeder is a net plutonium user - the plutonium is obtained from the discharges of LWRs - and the U-233 is bred in its thorium blankets.
Two different types of burners are used in this study : advanced CANDUs (DEU233-CANDU) and High Temperature Reactors (e.g. HTGR and Pebble Bed Reactors). These burners use denatured U-233 in uranium with thorium, as initial and makeup fuel. The sensitivity of the performance of the symbiotic system to the conversion ratio of the burner is also determined.

The symbiotic scenario calculations, involving nuclear fusion drivers, are performed for CTR-drivers in conjunction with denatured U-233 burners. The CTR-drivers are operated at a plasma performance parameter, Q, ranging from 1 to 10, injector efficiency, η_I=50%, heat-electrical conversion efficiency η_C=40%, blanket closure=95% or 85%, BOC power level at 1 Gwe.

The results of detailed calculations of overall fuel cycle and power costs, ore requirements, proliferation resistance, cash flow requirements, and capabilities for grid expansion of realistic symbiotic scenarios are presented. These calculations are based on detailed mass and energy flow balances and US INFCE[4] preliminary cost data, economic guidelines, and introduction constraints. An effective interest rate (without inflation) of 4.525%. and an appropriate sinking fund depreciation, are used. Taxes are not accounted for in the economic results. The method of indifference pricing is used. The sensitivity of the injector and breeder blanket heat removal costs on the U-233 production cost is also ascertained.
The high projected installed US nuclear power capacity, given by the US INFCE and NASAP[4] guidelines, is used up to year 2026, after which the on-line electrical power is kept at 910 Gwe. Pressurized LWRs operating on the stowaway uranium fuel cycle (LEU235-PWR) are introduced in year 1975; the advanced converters, LMFBR- and CTR-drivers are introduced in 2001, and the LEU235-PWRs are phased out starting in 2001. The effect of delaying reprocessing and introduction date of CTR- and LMFBR-drivers is also investigated. If U_3O_8 cumulative fuel resources are limited, an introduction of DEU235-Prebreeders and DEU233-Burners, or advanced LWRs is needed as an interim step.

The issue of the underutilization of the fusion fuel factory thermal installation at the beginning-of-cycle is studied. The excess heat, being generated in the blanket, increases with time during a cycle. Several approaches are used to include this effect in the power cost calculations:
1. excess heat removed as waste heat. 2. conversion to electricity,
3. part is converted, part is wasted. Also, shaping the plasma burn, so as to keep constant the blanket maximum power density improves the economics of fusion powered systems. Besides the generation of 910 Gwe, the use of HTR-burners gives the additional capability of producing synthetic fuel as steam reforming of methane (methanation).

As an example of the attractiveness of fusion powered fuel factories, the study shows that:
1. CTR-driven scenarios allow a plutonium throwaway mode, while the LMFBR-drivers require a plutonium stowaway mode and reprocessing for the LWRs.
2. The ratio of proliferation-proof advanced CANDUs (1 Gwe) to CTR-driver (e.g., Q=5, D-T, η_I=50%, heat-electrical conversion efficiency η_c=40%, blanket closure=95%, 1 Gwe) is as high as 44, versus 6 to 9 for the LMFBR-drivers. The CTR-driver has therefore a very high support ratio. 3. The high projected installed US nuclear power capacity is used. Typically, the overall bussbar power cost over 150 years of a LEU235-PWR/CTR(Q=5,D-T)/DEU233-CANDU symbiotic scenario is 14.4 mills/kwe-h and is not sensitive to the CTR fixed capital cost. The U-233 production cost is typically 65 to 120 $/g U-233 for the CTR scenarios studied. The LEU-235-PWR/LMFBR-driver/DEU233-CANDU overall power cost is 13.6 mills/kwe-h. The fuel cycle cost is 5.6 and 5.2 mills/kwe-h, respectively.
However, scenarios with CTR-drivers can follow power demand as long as thorium is available. LMFBR-driven scenarios cannot sustain the US INFCE high nuclear power demand.
4. The power doubling time of a CTR-driven scenario is smaller than a LMFBR-driven one, and much smaller than the doubling time of a pure plutonium-oxide heterogeneous LMFBR fast breeder system.
5. Based on economic, proliferation and technology considerations, there appears to be little incentive to attain a plasma performance parameter Q greater than 7 (at η_I=50%, maximum power density blanket=200 watt/cc) for metallic thorium blankets. Therefore, concepts which could not be considered for pure fusion reactors because of low plasma performance Q, can be considered for symbiotic fusion drivers in support of DEU233-burners.

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THE FUSION FISSION HYBRID - ROLES IN THE ENERGY ECONOMY

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EXTENDED ABSTRACT

The fusion-fission hybrid reactor consists of a fusion reactor and associated blanket which contains fissionable material. It is a versatile alternative energy source because it can be designed to produce electric power, fissile material to fuel fission power reactors or synthetic fuel to serve other markets. As a result it can fill many roles in the U.S. power economy. In this paper, we will discuss these roles.

The fusion-fission hybrid was first considered as a candidate for an alternative energy source in the early fifties [1]. The concept was abandoned shortly thereafter when the fusion driver proved much more difficult to build than originally envisioned and, thus, at the time other sources of energy and fissile fuel production appeared to be more viable. The concept resurfaced in the early seventies when advances in the development of magnetic fusion drivers gave promise that a hybrid reactor could be developed for energy production at an earlier date than pure fusion, since the plasma requirements for the hybrid are generally less demanding than for pure fusion. Later, the hybrid concept was extended to include inertial confinement devices as the fusion driver.

Whether magnetically or inertially induced, the common denominator of the hybrid devices is that the D-T fusion reaction produces a high energy (14 MeV) neutron that enters a blanket containing fertile material which surround the neutron source. It is the high energy of the fusion neutron from which the hybrid derives its versatility. This high energy allows considerable latitude in blanket design and, thus, various blankets for the production of power, fissile fuel, and/or synthetic fuel can be envisioned.

As a reference point for the wedding of the fusion and fission processes a conceptual hybrid reactor [2] will be discussed. A cross section of the reactor blanket is shown in Figure 1. From here, the various roles that such devices could play in the power economy will be described in greater depth.

These roles are:

- The hybrid can be utilized as a fissile fuel factory. In this role the hybrid reactor would produce ^{239}Pu from ^{238}U or ^{233}U from ^{232}Th for use in fission reactors. Since fissile material is used in the hybrid, safeguarding is a consideration in system design. In principal, the mechanisms involved to make fission breeder fuel cycles proliferation resistant should be applicable to the hybrid system.

- The hybrid can be designed as a stand alone power producer. Conceivably, the reactor blanket may be either enriched, natural, or depleted at startup. In any case the bulk of the power over the reactor's life would be generated from the fission of bred ^{239}Pu or ^{233}U and the fast fission of fertile material. It may be noted that a combination power and fissile fuel producer is another and perhaps optimal alternative.
- The hybrid reactor, because it has the potential for extremely high temperature operation, can be used for the production of hydrogen and other constituents for the making of synthetic fuels. The synthetic fuels would be used as a substitute for the currently used fossil fuels. In these roles of fissile fuel, synthetic fuel, or power producers, several options are available for enhancing the U.S. energy posture.
- Hybrids may be an alternative to the fast breeder should economic, environmental or other constraints prevent its introduction into the power economy. Even if the fast reactor is introduced at an early date, studies have shown there are still market opportunities for hybrid development and utilization. They could supply fissile fuel for fast reactor startup and/or existing light water reactors until such time as the fast reactor fuel cycles were self-sufficient.
- Since hybrids have the potential to be developed earlier than pure fusion, they could serve as a viable alternative source while supporting the technological development for the introduction of pure fusion at a later date.

We conclude by noting that since the hybrid has near term applications and long-term potential, it should be considered among the most promising of the alternate energy sources.

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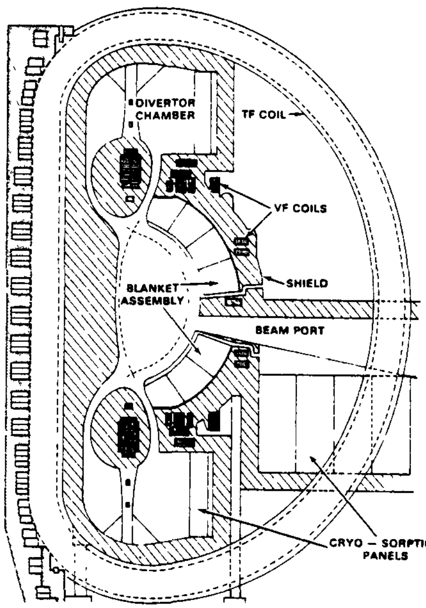

Fig. 1 - Cross-sectional view of a conceptual fusion-fission reactor. High energy neutrons produced from fusion reactions in the center of the device enter the blanket where various reactions occur to produce energy and/or fissile fuel.

STARFIRE - INITIAL CONCEPTUAL DESIGN OF A COMMERCIAL TOKAMAK POWER PLANT

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EXTENDED ABSTRACT

Argonne National Laboratory, in conjunction with an industrial team led by McDonnell Douglas Astronautics Company, and including General Atomic Company and the Ralph M. Parsons Company, is carrying out a comprehensive conceptual design study called STARFIRE of a commercial fusion tokamak power reactor and balance plant. The purpose of the study is to provide a mechanism for the U.S. Department of Energy to further assess the commercial potential of tokamak magnetic confinement for power reactors. The initial reference parameters for a helium cooled option are summarized in Table 1. This study is placing particular emphasis on utility requirements, safety and maintenance considerations.

TABLE 1. STARFIRE - INITIAL CONCEPTUAL DESIGN PARAMETERS FOR HELIUM COOLED SYSTEM

Fusion Thermal Power	3020 MW(th)
Total Thermal Power	3500 MW(th)
Net Electric Power	1000 MW(e)
Average Neutron Wall Loading	2.5 MW/m^2
Reactor Major Radius	7.2 m
Torus Aspect Ratio	3
Plasma Elongation	1.6
Plasma Average Toroidal Beta	8%
Toroidal Magnetic Field	3.8 T
Maximum Toroidal Magnetic Field Including Extra Field Margin of 1.7 T	9.0 T
Plasma Current	17 MA
Plant Availability Goal	75%
Plant Lifetime	30 years

The safety ramifications are being considered simultaneously with the evolution of the STARFIRE design. Efforts are being made to minimize the tritium inventory and the radioactivity induced in the candidate first wall and structural materials in the blanket and shield. Included in the calculations are the total radioactivity both during operation and after shutdown or removal, decay heat, total biological hazard potential in air and atmospheric dispersion following a hypothetical accident. Radiation levels in various portions of the plant during normal operation are also being calculated.

The design of the first wall and tritium breeding blanket is based heavily on a previous comprehensive review of possible blanket/shield designs [1]. Table 2 presents a summary of the combinations of coolant, tritium breeding and structural materials under study at this time.

TABLE 2. BLANKET OPTIONS

Coolant	He	H_2O	Li
Tritium Breeder	Li_2SiO_3*	Li_2SiO_3*	Li
Structural Material	FS/Ti	Ti/FS	V/FS
Neutron Multiplier	PbO	PbO	--

FS - ferritic steel

* Backup choices $LiAlO_2$, Li_2O

The first wall and blanket are designed as a separate system with only the necessary minimum of structural and mechanical interfaces to other reactor subsystems, to permit removal of complete first wall blanket circumferential segments for maintenance operation. Both inner and outer first wall and blanket regions are separate from the surrounding shield system, which has a design life equal to plant design life.

Major maintenance features of the design include large removal blanket sectors, location of the welded vacuum boundary in the benign environment of a fixed shield to assure reliable operation, use of redundant components in auxiliary reactor subsystems to minimize unscheduled shutdowns, EF coils that are raised and lowered for blanket removal, removable shield doors for blanket access, and open access to the top and sides of the reactor.

The reactor hall and remote/hands-on maintenance system is designed for frequent replacement of components that use simple push-pull operations. Items designed for the life of the plant include the overhead crane, TF coils, EF coils, coolant piping and radiation shielding. The blanket modules impurity control components, rf launchers, pumps, valves, fueling mechanisms, etc., are replaced on a scheduled basis. The spares for the superconducting EF coils trapped below the TF coils are stored in place so reactor disassembly is unnecessary in event of EF coil failure.

Availability goals have been established as 85% for the reactor and 75% for the complete plant including the reactor. The reliability of major subsystems has been assessed and allocations of time-to-repair and time-between-failures have been made. These criteria provide a basis for design of maintenance equipment. The maintenance scenario incorporates the current utility practice of shutting down annually for one month of maintenance and a 16-20 week shutdown every 10 years for turbine repair.

A particularly innovative feature that has been adopted for the initial conceptual design is the consideration of various ideas for sustaining the plasma current in a tokamak device, thus producing a steady-state reactor operating mode. Such an operating mode is expected to result in increased first wall lifetime and overall increased system reliability. Particular attention has been given to use lower hybrid rf waves for driving the plasma current.

Plasma current density profiles have been computed due to electron Landau dumping of lower hybrid waves launched into a variety of model density and temperature profiles. The total current and current profile shape are chosen consistent with the requirements of MHD equilibrium and stability against ballooning, ideal kink, interchange, and tearing modes. Toroidal magnetic fields of $\gtrsim 9$ T at the magnet, and very broad current profiles appear to result in the minimum rf wave power required to sustain steady state operation. In addition, plasma temperatures of $T_e = 16$ keV and the hot ion mode of operation ($T_i > T_e$) appear beneficial. A low aspect ratio ($A \approx 3$) is readily achieved for this design since there are no ohmic transformer windings at the center of the machine. It is possible to sustain steady state with 3% of the fusion power recycled as rf power to the plasma, provided narrow spectra lower hybrid waves can be launched with low refractive indices ($n_{\parallel} \approx 1.4$).

An important design consideration is the choice of plasma impurity/alpha particle removal concept. Several candidate concepts have been considered including torus limiter/vacuum pumping schemes, bundle divertors, gas puffing and plasma boundary flows, and additional margin in the toroidal magnetic field. Initial investigations indicate that modest pumping of helium with a limiter pumping system ($\sim$ 15% of the alpha particle flux) coupled with about a 1.7 T margin in the toroidal field may eliminate the need for a divertor, providing that a significant portion of the alpha particle energy can be radiated to the first wall rather than be deposited on the limiter.

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THE FUTURE OF FUSION POWER COMES INTO FOCUS

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EXTENDED ABSTRACT

INTRODUCTION

There has been a significant focusing of the effort to develop fusion power in the past year. A number of technical experiments have successfully verified our theoretical understanding and control of plasma behavior; our theorists have been conservative. With this assurance, and some dynamic leadership, the program has moved ahead more purposefully in many channels. Some of these channels are discussed to give a picture at this time of the thrust that is underway to build the future of fusion power.

Experimental Accomplishments - Five large tokamak and one mirror experiments started operation in 1978 and 1979. The Princeton Large Torus gave the fusion program a big impetus when it achieved a stable plasma at a temperature greater than 60,000,000 degrees centrigrade. The Impurities Studies Experiment-B at Oak Ridge has demonstrated impurity control and has injected fuel pellets into a plasma while maintaining stable operations. ISX-B is now investigating the maximum plasma pressures which can be sustained in tokamaks without instability. The Princeton Poloidal Diverter Experiment has demonstrated good plasma positioning and shaping control and is beginning to work on impurity removal. General Atomic's Doublet III has confined plasmas in both the upper and lower portions of the torus and filling the doublet shape. Neutral beam systems are now being emplaced for heating experiments. The Alcator family of experiments at MIT has pioneered investigations of high plasma density. Alcator-C promises to demonstrate for the first time the quality of confinement necessary for net energy production. The Tandem Mirror Experiment at Lawrence Livermore Lab began investigating ways to improve plasma confinement to increase energy multiplication factors of mirror machines. Experiments of plasma heating with radio frequency waves at Princeton and MIT have been very encouraging in the past few months. These six experimental devices are just beginning their productive phases which will see substantial increases in our knowledge of fusion in the coming months.

Reactors Being Built - The following generations of research units are being brought along very well. The Tokamak Fusion Test Reactor is taking form at Princeton on a schedule to begin operations early in 1982. The Mirror Fusion Test Facility configuration A is well along in building the

Yin Yang superconducting magnets. The MFTF-B tandem mirror design has been refined with a new thermal barrier and end cell concept.

Advanced Designs - The Engineering Test Facility Design Center group at Oak Ridge is in place with laboratory and industry members at full strength in October 1979. The International Tokamak Reactor study is well underway with the Russians, Japanese, Europeans and U.S. holding dialogues and making design decisions. A Commercial Tokamak design named STARFIRE is being developed by Argonne Lab and an industrial team led by McDonnell Douglas that will be optimized to meet Electric Utility Company requirements. This design will help focus technology developments and the data which must be generated by the Tokamak Engineering Test Facility. The current baseline design is described in the paper.

Program Strategies - A major replanning of the fusion program was initiated by the Department of Energy/Office of Fusion Energy in July 1979 with a large planning meeting of invited representatives from all segments of the fusion community. New strategies that can be followed under various funding plans have been described. OFE is prepared for aggressive changes in administration policy.

Congressional Realignment - Changes in committee and staff organizations and responsibilities have been made that affect fusion. The House Committee on Science and Technology formed a new Subcommittee on Energy Research and Production. Congressman McCormack, who chairs it, appointed a Fusion Advisory Panel headed by Dr. Robert Hirsch of Exxon. The panel has been briefed, studied the situation and have recommended that the fusion program technology warrants development at a more rapid pace. Committee oversight of Inertial Fusion was realigned in the House of Representatives.

System Test Facilities - Development of technology and advanced subsystems will be made in parallel with the plasma experiments. Some examples are given here. Neutral beam test stands at Oak Ridge National Lab and at Lawrence Berkeley and Livermore Labs are being upgraded for longer pulse runs. Materials irradiation facilities are proceeding with the High Intensity Neutron Source beginning operation at Lawrence Livermore Lab and the Fusion Materials Irradiation Test Facility conceptual design at Hanford. Management of tritium will be studied at the Tritium System Test Assembly which is being constructed at Los Alamos Scientific Lab. The Large Coil Test Facility is being constructed at Oak Ridge to test six superconducting magnets from six industrial sources; Japan, Switzerland, Euratom, General Dynamics, General Electric and Westinghouse.

Industrial Involvement - The participation of industry in the fusion program has expanded recently from parts supplier and fabricator to become more of a partner with the fusion laboratories. To do the job of conceptual design of the Engineering Test Facility, the knowledgable laboratories have chosen industrial teammates and will share the monies at least 50-50. On this, and on other programs, industry is gaining the knowledge and experience to manage system tasks in preparation for the time when fusion power plants must be designed and produced for the utility company user. This focusing of activity indicates that fusion is maturing. The fusion program managers are moving ahead with confidence that fusion power can be available on or before the schedule now being followed.

SESSION 2D

COAL TECHNOLOGY I

THE PRICETOWN I UNDERGROUND COAL GASIFICATION FIELD TEST

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ABSTRACT

Underground Coal Gasification provides a unique means of extracting energy from coal deposits not recoverable by conventional techniques. The potential exists for quadrupling the coal resources economically recoverable while, at the same time, eliminating many of the health, safety, and environmental problems generally associated with conventional mining and above-ground gasification.

A field test of the linked vertical well technique of underground gasification has been completed in the Pittsburgh bituminous coal seam at a test site near Pricetown, West Virginia. This test was the first to be conducted in the deep, thin bituminous seams and provided valuable experience and in-situ data required for the development of first generation UCG concepts.

Data collection and operation were facilitated by an automatic, computer based monitoring, control, and analysis system. The test process design and the test strategy are presented along with field test results.

*Mound Facility is operated by the Monsanto Research Corporation for the U. S. Department of Energy under Contract No. DE-AC04-76-DP00053.

LIGNITE COMBUSTION IN FLUID BED COMBUSTOR-UTILITY APPLICATION

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ABSTRACT

Experiments conducted at Morgantown Energy Technology Center (METC) and Grand Forks Energy Technology Center (GFETC) have shown that lignite can be successfully burned in a Fluid Bed Combustor (FBC). The combustion of lignite in FBC does not have the kind of problems which are found during the combustion of high sulfur bituminous coal in an FBC unit. The volumetric heat release rate due to combustion of lignite is identical to that obtained due to combustion of bituminous coal in FBC unit. The rate of carbon utilization is high and a Carbon Burnup Cell (CBC) is not required in a lignite fired FBC. There is very little or no combustion taking place in the free board or near the bed surface. The current sulfur dioxide emission standard can be met with little or no sorbent addition, provided the bed is operated at a temperature below 1600^{o}F. The proposed federal EPA emission standard on sulfur dioxide can be met by addition of limestone to bed. The required calcium to sulfur mole ratio is equal to or slightly greater than 1.0.

Conventional lignite boilers are 34% to 94% larger than bituminous coal fired boilers on a volumetric basis. The size of the conventional lignite fired boiler increases depending on the ash content and heating value of the lignite. The use of atmospheric fluid bed boiler burning lignite offers a potential saving in the size of the boiler compared to conventional lignite fired unit. It is shown that up to 20% saving in capital cost and 15% saving in cost of electricity can be obtained by the use of atmospheric fluid bed boiler burning lignite in utility application. The application of FBC technology opens a new avenue for the utilization of lignite resources of the Gulf and Northern Plains of the nation.

ECONOMICS AND CONCEPTS OF INDUSTRIAL COAL FLUIDIZED BED COMBUSTION IN BRAZIL

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Brazil is among the developing countries which has suffered considerably with the recent constant increases in oil prices. Brazil is short of natural gas, present production of indigenous oil accounts for less than 20% of consumption and its transportation and industrial structures are heavily based on petroleum. To maintain its present growth rate and standards the energy planners and policy makers in Brazil face the problem, in the short run, of meeting the increasing demand for energy with whatever source is most readily available and using an efficient and economically established technology.

Present measured and inferred reserves of Brazilian high ash coals are large, and have been virtually unexplored commercially, metallurgical coal utilization aside. Steam coal consumption has lagged behind production for a number of years, resulting in large stocks of coals with different, even dissimilar characteristics. Fluidized Bed Combustion is therefore an alternative which seems promising in Brazil, for its inherent ability of accepting different fuels in a given system.

This work analyzes the feasibility of producing steam in fluidized bed boilers burning Brazilian coals as compared with other alternative systems such as stoker firing, oil-fired and electric boilers.

The range of boiler capacities selected for the study is typical of the boilers found in Brazilian industry, namely 5 to 30 metric tons per hour of steam.

Since present Brazilian environmental legislation does not presently pose any restrictions on the emissions of sulfur dioxide, the analysis did not consider flue gas desulfurization for stoker fired boilers neither injection of limestone in the FBC boiler. Evidently, when legislation to control SO_2 is introduced FBC systems can be easily made to comply with little added investment whereas stoker fired boilers would have to incorporate expensive gas scrubbers.

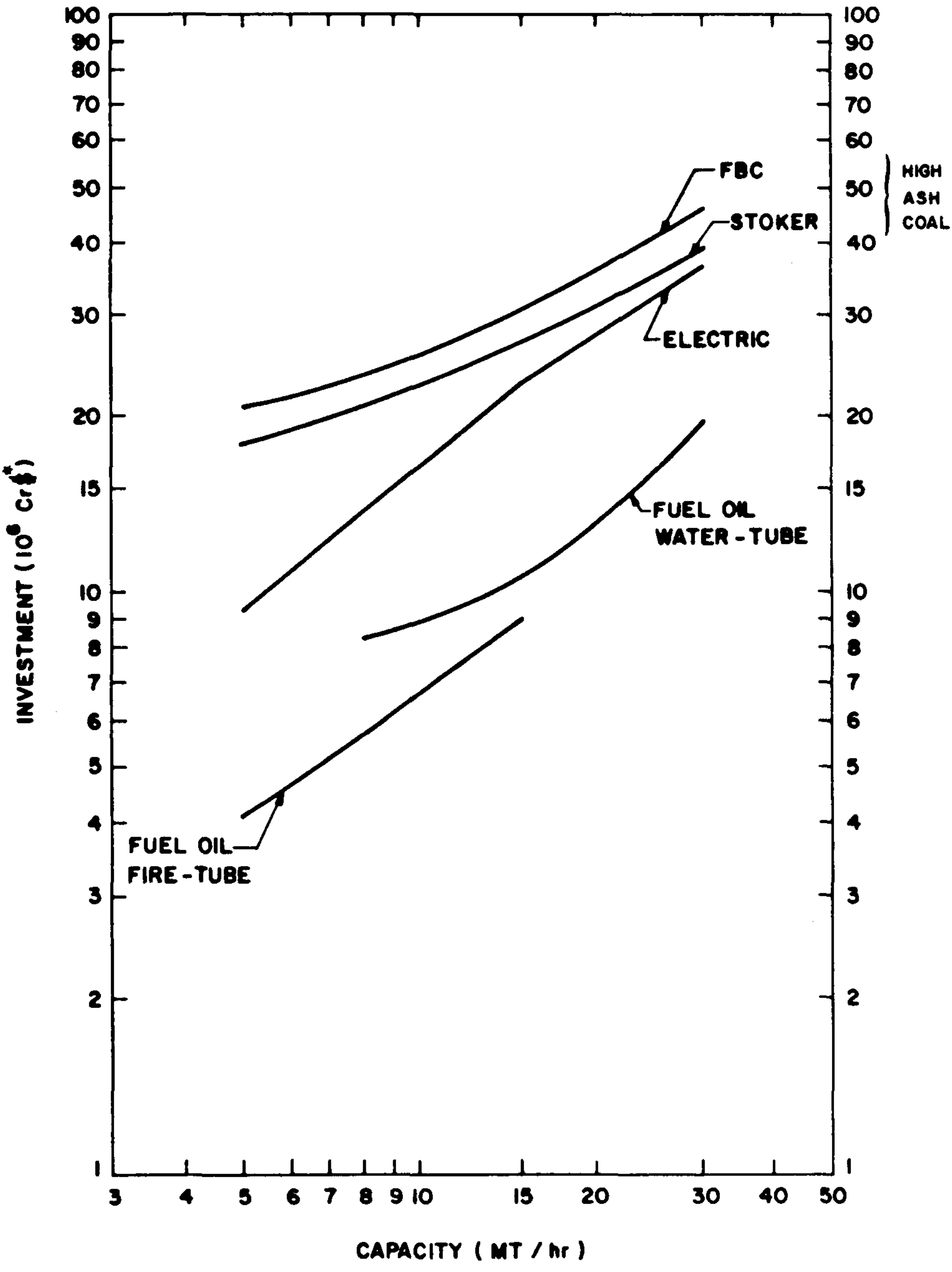
Particulate emissions were assumed to be limited to 800 mg/m^3 for all systems considered in the analysis.

Both investment and cost of steam were computed for the five alternatives. Figure 1 shows the total investment as a function of capacity.

It was concluded that although FBC systems are somewhat costlier than stoker firing this difference is of the order of magnitude of the uncertainties involved in the analyses and it was shown that due to the highly subsidized coal prices in Brazil the use of coal in industry is competitive with all the alternatives considered.

Coal fired fluidized bed boilers will therefore become quite attractive for being economically competitive with stoker fired boilers and particularly for presenting added advantages concerning the flexibility of fuels and the possibility of in-bed desulfurization.

COMPARISON OF INVESTMENTS FOR THE BOILERS CONSIDERED IN THIS STUDY



*30 Cr$ (September 1979) = 1 US$

COMBUSTION OF COAL SUSPENSION FUELS USING AIR ATOMIZERS

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EXTENDED ABSTRACT

INTRODUCTION

Pulverized coal may be dispersed in various liquid fuels to form combustible fluid mixtures which are variously called colloidal fuels, fuel slurries, and suspensions. These mixtures have several features which make them attractive as fuel alternatives. Relatively expensive liquid fuels are augmented by more plentiful, cheaper coal. Total sulfur content remains low when the liquid phase is low in sulfur. In cases where a low BTU liquid fuel is used, the heating value may be boosted by the addition of the coal. Finally, pulverized coal can be delivered to the combustor like a liquid fuel which aids in reducing clogging and erosion.

Suspending coal in a heavy fuel oil is an old concept which has recently been receiving renewed attention as a boiler fuel. It is also possible to suspend coal in lighter petroleum fuels and alcohols. These types of suspensions could replace current fuels in turbines, industrial burners, or Diesel engines providing problems with slag and wear can be overcome.

Considered as a group, air atomizers appear well-suited for handling coal suspension fuels. Air atomizers include several different types of devices which achieve atomization by the action of an air jet at the fuel nozzle to disrupt the fuel stream. This type of atomizer is contrasted to pressure nozzles which supply very high fuel. A common example is the plain jet atomizer wherein the air and fuel flow concentrically. Disruption of the fuel stream takes place at the interface with the liquid droplets entrained downstream in the spreading gas jet. A gentle fuel spray cloud with broad angle may be produced. Air atomizers have been shown to be effective in reducing pollutant formation in the combustion of liquid fuels. Furthermore, because of the relatively large fuel orifices, clogging may be reduced.

EXPERIMENT

Experiments have been conducted in a water jacketed flame tube fitted with observation ports. The atomizer injects fuel into the wake of a disc baffle used to stabilize the flame. Measurements of exhaust gas temperature and temperature rise in the water jacket yield the total energy release. From knowledge of the heating value of the mixture, the overall thermal performance of the suspension fuel can be computed. Thermal efficiency is reported on a comparative basis, between the suspension fuel and the pure liquid and with other suspension types.

Several fuels were tested including Diesel No. 2, Jet A and light alcohols in various combinations with bituminous, lignite and solvent refined coal. Most suspensions were prepared by mechanical grinding and sieving. Constant agitation was required to keep the mixture homogeneous.

RESULTS AND DISCUSSION

Most fuel types tested performed well in conjunction with air atomizers. Comparisons have been made between suspension types using several atomizers. A detailed study of the combustor indicates that, in general, as gas velocity increases less energy is deposited in the cooling jacket. This trend is reflected in the figure, which shows the energy distribution as a function of the equivalence ratio, actual fuel flow/ideal fuel flow.

The combustion of coal liquid suspensions is complex, depending on particulate size and characteristics, type of liquid fuel and the atomization process. An analysis of the characteristic time scale involved in each step of the combustion particles indicates that coal in larger size ranges (80μ) ignites and burns relatively slowly in comparison to most liquid fuels. This means that the residence time of the coal particle in the combustor must be long for complete combustion or the coal particles must be very small.

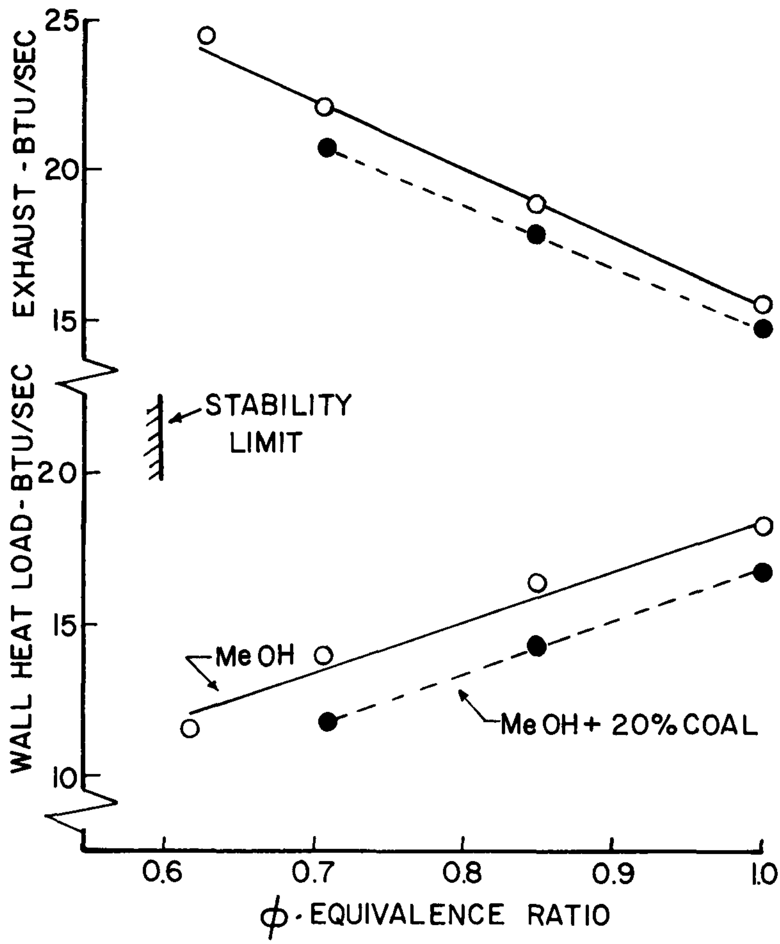

Fig. 1. Effect of excess air on energy deposition--wall heat load and exhaust gas enthalpy

FLUIDIZED BED COMBUSTION OF COAL

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EXTENDED ABSTRACT

INTRODUCTION

As was made specifically clear at this June's Tokyo Summit, with the by-nation and by-year setting of upper limits of oil imports, both the shortage of supply of oil products and their resultant price rises are inevitable. Therefore, the role of coal is becoming increasingly important as an alternative to petroleum. It is for this reason that the most efficient techniques available for the utilization of this fossile fuel are to be hoped for.

Among the various techniques used in the utilization of coal, the fluidized bed combustion boiler (FBB) has attracted a great deal of attention for a number of reasons, among them being: it assures low-pollution combustion; it cuts down on energy generation costs, since with the fluidized bed combustion boiler no facilities, themselves expensive, are required for the removal of NO_x or SO_x compounds; development of the FBB for practical application is close at hand, since there are but a few technical problems yet to be overcome (in fact, several pilot plants are already in operation).

In Japan, where environment protection regulations are among the strictest to be found anywhere (hence in Japan the development targets for FBB are 60ppm or less NO_x emission and 95% or better in desulfurization efficiency), the highest priority is naturally given to the reduction of NO_x emission and improvement of in-furnace desulfurization efficiency, in the research and development of the fluidized bed combustion boiler.

Kawasaki Heavy Industries (KHI) first began the basic research and development of fluidized bed combustion technology in 1975. Since then various tests have been conducted using different fuels: heavy oil, COM and various types of coal. And KHI has also been taking part in a cooperative effort with the Coal Mining Research Center and other parties, in a mammoth

R & D effort under the auspices of the Japanese government, the Fluidized Bed Combustion Boiler Development Project. In this project we have successfully brought NO_x emission levels to within 50ppm and raised desulfurization efficiency to 93%, which is to say that we have come very close to achieving the above-mentioned targets for domestic application in Japan. At present we are engaged in the planning of a pilot plant whose evaporation is 20 tons per hour, to be completed in 1981.

TEST ITEMS AND EQUIPMENT

In the combustion test, two test combustors were used which were similar in construction but different in size; one measured 200mm square and the other, 500mm square. As test coal, Taiheiyo coal and Miike coal were used, and natural limestone was employed as sorbent.

Composition of combustion gas was continuously measured and recorded by a magnetic O_2 analyzer, a chemi-luminescence NO_x analyzer, and NDIR type CO and SO_2 analyzers.

Shown below are the items which the authors investigated through testing:

Step I: Normal combustion test (no staging)
1) Effects of various parameters on combustion efficiency
2) Effects of various parameters on NO_x emission
3) Effects of various parameters on desulfurization efficiency

Step II: NO_x reduction test
1) NO_x reducing effect of two-stage combustion
2) NO_x reducing effect of multi-stage combustion
3) NO_x reducing effect of NH_3 injection

Step III: NO_x and SO_x simultaneous reduction test
1) Reduction of NO_x and SO_x emission by two-stage combustion

TEST RESULTS

In the course of our research, the effects on NO_x, SO_x and CO emissions and on combustion efficiency were studied by changing various operating and equipment parameters, with the result that optimal operating conditions were determined. The main parameters employed in the series of tests were air ratio, primary air ratio, bed temperature, heat release, bed height, freeboard height, secondary air injection height, coal particle diameter, and Ca/S mole ratio.

In the Step I tests, the relation between NO_x emission, CO emission, SO_2 emission and combustion efficiency was made clear. Specifically, requirements for enhanced desulfurizing and high combustion efficiency were compatible, but they were incompatible with the requirements for optimal NO_x abatement. Furthermore, combustion efficiency was greatly affected by such parameters as heat release, bed temperature, air ratio and coal particle diameter, while desulfurization efficiency was influenced extensively by parameters including heat release, bed temperature, Ca/S mole ratio and air ratio. The factor with the greatest impact on NO_x emission was air ratio.

In the Step II tests we found that two-stage combustion is very effective in the reduction of NO_x emission. With coal of 1% N content, as little as 50ppm NO_x emission was achieved. It was also found that the main parameters having an important impact on NO_x emission in two-stage combustion were primary air ratio, secondary air injection height, and heat release. By adding NH_3 (NH_3/NO_x mole ratio = 1), NO_x emission could be reduced by about half; in this case, such factors as bed temperature, NH_3/NO_x mole ratio and NH_3 injection height had much to do with the test results.

The goal of the Step III test was to determine the optimal conditions for effective NO_x reduction and desulfurization--whose requirements are mutually incompatible, as mentioned above. And it was found that by carefully choosing the freeboard height, secondary air injection height, sorbent particle diameter, primary air ratio and bed temperature, it was possible to prevent significant drop in desulfurization efficiency in two-stage combustion; that bed temperature exerts a great effect on desulfurization efficiency, and optimum temperature for combustion is lower than that for conventional combustion (no staging).

CONCLUSION

Through the combustion tests where various parameters were varied to obtain enhanced combustion, desulfurization efficiency and effective reduction of NO_x emission, the authors could clarify various mutual effects taking place in fluidized bed combustion. Further, during this period of testing, highly favorable test values could be achieved--specifically 50ppm NO_x emission and 93% in desulfurization efficiency. These results fall slightly short of our original targets of 60ppm or less NO_x emission with 95% or better desulfurization efficiency, but the authors are confident that the targets can be attained in the near future. Hence they see bright prospects for the completion of a fluidized bed combustion boiler requiring no flue gas desulfurization or denitrification plant, thereby easily conforming to stringent environmental control regulations in Japan.

"CHEMICAL TREATMENTS FOR GASIFICATION OF CAKING COALS"

BY

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ABSTRACT

Many gasification processes cannot be fueled with caking or strongly swelling coals. In the absence of oxidative treatment such coals cause pluggage and interrupt gasifier operation. Although some gasifier designs can accept virtually any coal for gasification, the majority require a pretreatment of the fuel. This pretreatment typically involves the superficial oxidation and devolatalization of the fuel in a heated zone. Volatile components which would otherwise agglomerate the fuel injected into the gasifier are removed rendering the coal non-caking and suitable for consistent operation.

Pretreatment requires a significant energy input into the system and often the fuel values of volatilization materials are lost to the process.

This report elaborates the problems encountered in the gasification of caking coal and examines methods of pretreatment including the use of chemical additives as an alternative to partial oxidation.

COAL OIL MIXTURES: THE DIVERSITY IN THEIR RHEOLOLOGY AND STABILITY CHARACTERISTICS

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INTRODUCTION

There are many technical and economic impediments to the conversion of existing oil-fired boilers especially utility boilers, to direct 100% coal utilization. These ipediments include; the costs of modifying old oil design boilers to burn coal; major expenditures for solids transport means, as well as for coal unloading, storage, handling etc.; the non-existence at the sites of many plants, of space for the above services.

However, the utilization by a utility or industrial plant, of coal as a commercial fuel product mixed with fuel oil, could overcome the above problems. Coal oil mixtures (COM) can be handled either in transportation or at the plant as liquid fuels, utilizing existing carriers, storage tanks, pipelines and burners.

A fundamental requirement in the commercial utilization of COM is that a fuel of known and constant composition be delivered on demand at known rates. However, due to the variable and heterogeneous nature of the coal particles, the complex nature of the oil and the use of additives selected from thousands of possible candidate substances, COM can be prepared with appreciable differences in rheological behavior, in settling, in the effect of applied shear (agitation and pumping) and in particle aggregation.

2. CHARACTERIZATION OF COM SLURRIES

In our studies three extreme states of suspension for COM were identified qualitatively:

Type (I) suspensions in which the coal particles retain their individuality i.e. they do not form clusters. Such suspensions are considered aggregatively stable.

Type (II) suspensions in which the particles interact and form a three-dimensional network of clusters throughout the volume of the suspension. Such a system is sedimentatively stable.

Type (III) suspensions in which the particles irreversibly aggregate to form large individual agglomerates. Such a system is unstable in both the sedimentative and aggregative sense.

COM of intermediate suspensions states have also been prepared.

The behavior of COM in transportation storage, flow and combustion will undoubtedly be affected by the type of suspension. Thus, the development of a quantitative system for COM type characterization and classification is crucial.

A model recently developed involves characterization of COM systems by three parameters:

a) the sedimentation number, which reflects the extent to which particles have settled from a top layer in a sedimentation column.

b) the aggregation number, which reflect the extent to which the coal particles have irreversibly agglomerated.

c) the gelation number, which reflects the rheological properties of the COM.

3. FACTORS AFFECTING THE CHARACTERIZATION PARAMETERS.

Examples of data will be presented indicating the effect of various additives on the production of various COM types. The effects of additives may be explained on their ability to modify the hydrophilicity/hydrophobicity ratio (philicity) of the coal surface.

Philicity appears to be an important coal property for COM preparation. Coals differ in philicity and consequently lead to different COM types.

It will be also shown that water by itself or in combination with additives is an important variable affecting the characterization parameters of COM.

4. OPTIMUM COM TYPE

The question "what type of structure is the optimum for all stages of COM preparation and utilization?" has not been answered yet. Work designed to answer this question will be outlined.

THE FEASIBILITY OF USING COAL TO HEAT AND COOL PUBLIC BUILDINGS IN WEST VIRGINIA

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EXTENDED ABSTRACT

Conversion of the State and municipal public buildings of West Virginia to coal-fired heating plants has been investigated in detail. The study was prompted by local fuel shortages during the severe winter of 1976-77 and funded by the West Virginia State Legislature. It was conducted during 1977-78 by a multidisciplinary team of faculty members from West Virginia University and West Virginia Institute of Technology with funding (excluding overhead) of $277,000. The methodology, analysis, and results of the study can provide guidance to other states or regions seeking to reduce dependence on foreign oil sources or trying to deal with the world energy crisis projected to occur between 1985 and 1990.

The study included an individual, detailed analysis of converting each of eighteen college and university campuses to coal-firing, as well as detailed analyses of selected schools, institutions and other public buildings. The study also involved the classification of similar types of public buildings and analysis of that classification type. The investigations included evaluation of various coal-fired technical alternatives, equipment availability, and capital costs; the availability of coal, coal costs, and coal transportation problems; the impact of air, water and solid waste pollution, pollution control equipment selection and costs; operational and maintenance requirements; the effects of conservation modifications on reducing overall costs; and an overall economic analysis.

The major constraints of commercial availability, a maximum steam rate of 150,000 lb/hr and the combustion of bituminous coal resulted in the utilization of commercially available stoker-fired steam boilers equipped with baghouse particulate collectors. The required stoker coal costs two to three times as much as typical steam coal, and must contain less than 2.1% sulfur to eliminate the need for sulfur oxides removal equipment. In areas with more stringent air quality standards, coal gasifiers with sulfur removal equipment can burn high sulfur coal with little economic penalty over conventional systems with sulfur cleanup. Water (boiler blowdown) and solid waste (ash) pollutants are found to be easily handled by local sewage treatment or landfill at most sites. Central heating plants are recommended at most campus and institutional locations to minimize air pollution, coal storage, and coal transportation problems. Operational and maintenance costs are considerably higher for coal-fired units over oil or gas-firing, because of the added attention required. Two-man shifts required at high

pressure central plants make central plant operation economically viable only for the largest plants considered. The conservation modifications of additional roof insulation (to meet or preferably exceed ASHRAE 90-75) and double pane windows usually reduce initial capital costs because of reduced boiler capacity required, and obviously reduce operating expenses.

Under current regulated fuel costs and operational constraints, the economic analysis indicates an overall savings to investment ratio of about 0.3, which is much below the breakeven point (1.0). Considering intrastate gas prices or proposed new ceilings on interstate prices the SIR could double. Considering the question of availability of energy and jobs and of maintaining heat in hospitals, the values are extremely competitive.

Converting 3,580 major buildings out of West Virginia's 6,098 State and municipal buildings to coal-firing would have an initial cost of about 20% of the State government's annual income, with an additional annual operating cost of 2.5%. The savings in natural gas would be about 5% of the annual consumption. Coal requirements are approximately 0.3% of the State's annual production. Labor requirements are 5% of those currently unemployed. Conversion to coal is considered financially possible, and should not produce adverse economic impact unless it is done in haste without long-range planning and gradual implementation.

SESSION 2E

HYDROGEN ENERGY I

OVERALL EFFICIENCIES FOR CONVERSION OF SOLAR ENERGY TO A CHEMICAL FUEL

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EXTENDED ABSTRACT

INTRODUCTION

Without question sufficient sunlight falls on earth to supply a fully populated planet with abundant energy. The problem is that this energy arrives in a diffuse and intermittent manner. For sunlight to be a major primary energy source, it must be converted to a concentrated and storable form (e.g., chemical fuel) at a practical efficiency and at a reasonable cost.

The proposed methods for conversion of solar energy to chemical fuel include: 1) conversion of concentrated sunlight to electricity in a conventional thermal cycle followed by hydrogen production via water electrolysis; 2) thermochemical conversion (e.g., water splitting) with concentrated solar energy as the heat source; 3) photovoltaic conversion to electricity followed by water electrolysis; 4) photogalvanic conversion to electricity followed by water electrolysis; 5) direct photoelectrolysis of water; 6) natural photosynthesis followed by pyrolysis, fermentation, or digestion of the biomass to convert it to a more convenient form; and 7) direct photochemical production of hydrogen or some other chemical that is capable of undergoing exothermic conversion back to the starting material.

ANALYSIS OF CONVERSION PROCESSES

Extending the work of Schneider [1] and that of Porter and Archer [2], it is demonstrated that the overall efficiency of each of the seven processes above is determined completely and consistently by ten common factors: 1) maximum theoretical efficiency; 2) inherent absorption losses; 3) inherent internal losses; 4) rate limiting effects; 5) reflection losses; 6) transmission losses; 7) coverage losses; 8) system construction requirements; 9) parasitic losses; and 10) harvesting and conversion losses.

Both state-of-the-art and optimistic values are assigned to each factor for each of the seven conversion processes. State-of-the-art overall efficiencies range from ~10-15% for thermal conversion down to essentially zero for the undeveloped thermochemical and quantum processes. Optimistic values for overall efficiencies in the range of ~20-25% are calculated for several of the processes. Although these efficiencies may seem low, higher reported efficiencies typically do not include all ten of the factors discussed and accounted for here. For example, a commonly ignored factor is the coverage factor defined as the ratio of the area of the active elements of the system to the total area within the boundaries of the system. While not strongly effecting the cost of the system, this factor is important in comparing the amounts of land area required by various processes.

CONCLUSIONS

Based on the work that has been done to date, thermal conversion, natural photosynthesis, and photovoltaic conversion are far ahead of the other solar energy conversion schemes with respect to practical feasibility.

In addition, estimates of the energy cost for the first two of these schemes are approaching present day energy costs. Predictions are that the cost of photovoltaic conversion will also be reduced eventually to a competitive level by research efforts that have already begun to bear fruit [3].

All of the other conversion schemes have serious practical limitations, the primary one being actual efficiencies much lower than those predicted. Even so, they are of considerable scientific interest and have some intriguing possibilities. What we must keep in mind, however, is that not only must they work but also they must compete economically with the three more promising approaches.

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BIOPHOTOLYSIS SYSTEMS FOR H_2 PRODUCTION

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EXTENDED ABSTRACT

Model systems containing natural and synthetic catalysts were constructed for the production of H_2 from water using visible solar radiation as the energy source. Chloroplast membranes were used for light absorption and photodecomposition of water; ferredoxin, flavodoxin, cytochrome, viologen dyes, "Jeevanu" particles or synthetic clusters containing Fe-Mo-S centres were tried as electron transfer catalysts and hydrogenase or PtO_2 served as proton activator. We have also investigated the use of illuminated aqueous systems with proflavine and an electron donor for water photolysis and subsequent production of H_2 when coupled to electron mediators and hydrogenase (or Pt). The characteristics, and relative merits and defects of these systems are discussed.

We are continuing our investigations on H_2 production from water, in the presence of biological and synthetic catalysts, using the sun as energy source. Our basic experimental system consists of a buffered suspension of isolated chloroplast membranes, the enzyme hydrogenase and an electron carrier which transfers electrons from water, via the chloroplast components, to the hydrogenase [1-4]. When such an in vitro system is illuminated (11000 lux) H_2 gas is liberated continuously; the rate and duration of H_2 evolution depending on the source of chloroplasts the nature of electron mediators and hydrogenase and the oxygen content of the system. We have reported rates of 50 μmoles H_2 liberated per mg chlorophyll per h, constant for 4 h. In the past two years we have been concentrating our efforts to stabilize the system for maximum yield of H_2. These included isolating the biocatalysts from various natural sources and testing their relative efficiencies and searching for synthetic substitutes for the biological components of the system.

Among chloroplasts isolated from various plants those from Chenopodium spp. were found to be the most stable in the light. The dark stability of the chloroplasts can be improved by the addition of bovine serum albumin. Crosslinking with glutaraldehyde and bifunctional reagents, incubation with lipases and antioxidants and binding to calcium alginate were some of the techniques used to overcome photoinhibition of chloroplast activity. Of these embedding the thylakoids in calcium alginate seems to be promising [5] .

Hydrogenase from Clostridium pasteurianum is extremely active and couples very effectively with chloroplast ferredoxins and flavodoxins; this enzyme however is very sensitive to oxygen. The enzyme can be made more stable by coupling to sepharose-bound ferredoxin. Another hydrogenase which can be used in the system is that from Desulfovibrio sp.;

D.gigas or D. desulfuricans, strains 9974 or Norway. Recently D. gigas hydrogenase was immobilized by binding to aminospherosil beads (Hatchikian, C. & Monsan, P. Marseille) and this immobilized enzyme was able to liberate H_2 from illuminated chloroplasts with methyl viologen or cytochrome 'c_3' as mediator. Oxygen and heat-stable hydrogenases from a number of sources were tested in the system and the results are shown in TABLE I. It can be seen from this Table that there are a number of permutations possible for H_2 production.

TABLE I

COMPARATIVE ACTIVITIES OF HYDROGENASES

Source of hydrogenase	Electron mediator and concentration in μM	μ mol H_2/ h/ mg chlorophyll
Clostridium pasteurianum	FD 15	45
	FD 15	22*
	FLD 18	18
Alcaligenes eutrophus	MV 50	6.0
	" "	12.0*
Methano bacterium thermoautotrophicum	FD 15	1.0
	MV 25	13.0
D. desulfuricans Strain 9974	FD, 2.5 + C_3, 1.25	19.0
Strain Norway	FD 15	5.0
	MV 25	21.0
Spherosilbound D. gigas	MV 100	6.4
Thiocapsa roseopersicina	FD 25	14.5

The reaction vessels contained the respective hydrogenases and mediators, 100 μg chlorophyll, 1000 units catalase, 20 units glucose oxidase, 10 μl ethanol & 100 μmoles glucose in 2 ml 50 mM HEPES buffer. Light intensity 11000 lux. Hydrogen evolved was measured using a gas chromatograph.

*No oxygen scavengers in the system. FD, ferredoxin, FLD, flavodoxin, MV, methyl viologen.

The natural electron carriers which function with hydrogenases are ferredoxins, flavodoxins, cytochromes and NADH. Methyl and benzyl viologen are the widely used artificial electron carriers in the H_2 evolution reactions. We have had a fair amount of success in replacing the above mediators with "Jeevanu" and a thiolated cluster $[NEt_4]_3$ $[Fe_6\ Mo_2\ S_8(SCH_2\ CH_2OH)_9]\ Me_2\ CO$. "Jeevanu" particles are obtained by exposing to sunlight solutions containing ammonium molybdate, $(NH_4)_2$ HPO_4, HCHO and one or more metals such as Ca, V, Co, Mn, Zn etc [6]. These particles (kindly donated by Dr. K. Bahadur, Allahabad University) in aqueous suspension liberated H_2 from illuminated mixture of chloroplasts and C. pasteurianum hydrogenase though the rates were only 10% of those observed with ferredoxin as mediator. The molybdenum containing cluster [7] was able to substitute for ferredoxin in H_2 evolving systems.

Methyl viologen can be photoreduced by EDTA and other organic compounds when illuminated in the presence of proflavin. Krasna [8] has recently reported the characteristics of this system when adapted for H_2 production. We too have made extensive studies of this system using combinations of various electron donors and hydrogenases or PtO_2 (Adam's catalyst). The main drawback of the chloroplast system is the gradual deterioration of Photosystem II activity on continued exposure to light and oxygen. Much more intense research is required in this area to devise techniques for light-stabilisation of chloroplast activity. The proflavine system, though it dispenses with chloroplasts, requires expensive electron donors since it cannot split water. Platinum catalyst is also sensitive to oxygen. A number of stable hydrogenase preparations are now available.

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HYDROGEN GENERATION FROM THE CHLOROPHYLL WATER SPLITTING REACTION PHOTOCHEMICAL CONVERSION AND SOLAR ENERGY STORAGE

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In this paper we present a detailed product analysis for the water photolysis reaction of microcrystalline chlorophyll a dihydrate. The generation of H_2 and O_2 was established by mass spectrometric determination. The stoichiometry of water splitting was examined by calibration against conventional electrolysis. The observation of O_2 evolution in water photolysis was accomplished by the establishment of binomial distributions of ${}^{16}O_2^+$, ${}^{16}O^{18}O_2^+$, and ${}^{18}O_2^+$ obtained from ${}^{18}O$-enriched water. The determination of isotopic distributions in the hydrogen evolved from the photolysis of D-enriched water was made difficult by instrumental artefacts (nonlinear line-intensity effects) in the mass 2 - 4 region and by molecular fragmentation in conventional mass spectrometry. The complications were eliminated by using ion cyclotron resonance techniques. At 17 eV, an ion-source voltage below the appearance potentials for the cracking of H_2 and H_2O, the expected random-scrambling distribution in H_2^+, HD^+ and D_2^+ line intensities was obtained in the photolysis of D-enriched water. It was found that pure $(Chl\ a \cdot 2H_2O)_n$ is capable of photocatalyzing water splitting, and that this capability is greatly assisted by Pt. These results are discussed in terms of the facilitation of gaseous oxygen evolution at the catalytically active sites on the Pt surface. The properties of $(Chl\ a \cdot 2H_2O)_{n \geq 2}$ as photocatalyst for the water photolysis reaction are interpreted in terms of the molecular interactions across water linkages connecting the adjacent Chl a molecules in $(Chl\ a \cdot 2H_2O)_n$. The maximum experimentally observed photoconversion efficiency is obtained, and the inhibitive effects of the oxygen on the photolytic rate are discussed in terms of the molecular dimensions of the $(Chl\ a \cdot 2H_2O)_{n \geq 2}$ aggregate.

We describe the photoconversion and storage of visible light energy based on the half-cell reactions of water photolysis by crystalline chlorophyll dihydrate multilayers on platinum foils. The gaseous products, H_2 and O_2, liberated concomitantly with the photogeneration of electricity, are analyzed by mass spectrometry. We investigate the mechanisms for electroplating Chl a from a 5×10^{-3} M n-pentane suspension of $(Chl\ a \cdot 2H_2O)_n$ microcrystals on Pt foils under light and in the dark. The disintegration and reorganization of $(Chl\ a \cdot 2H_2O)_n$ microcrystals into a contiguous multilayer film on the Pt substrate under an applied electric field is established by electron microscopy. The quality of the multilayer is examined by a quantitative analysis of the amount of Chl a electrodeposited and the photocathodic activity of the resulting Pt/Chl a electrodes in terms of the plating field. The role of the metal substrate in the water photolysis reaction, related to the rate and overvoltage for gaseous O_2 evolution, is probed by determining the photocathodic activity of a single Pt/Chl a electrode against four different metals, Pt, Cu, Fe, and Ni, interchangeably employed as the counter electrode (anode). The order Cu > Ni > Fe > Platinized Pt > shiny Pt is observed for the relative effectiveness of these metals as counter electrodes for the Pt/Chl a photocathode at photocurrent densities $\lesssim 10^{-1}$ μA in oxygen-depleted aqueous solutions. The experimental behavior of light-induced decay and dark restoration of the photogalvanic activity is described in terms of a kinetic model for the production and removal of oxygen at the counter electrode. Photocurrents on the order of 1μA are generated by monochromatic red light from a Xenon-Arc source. A quantum efficiency of 0.88% was obtained at the red maximum, 735 nm, of the photogalvanic action spectrum.

PRODUCTION OF HYDROGEN FROM BIOMASS

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ABSTRACT

Rockwell International is investigating a novel method for the utilization of biomass and organic wastes for the production of hydrogen from water. This process, referred to as the Bromination Process, consists of a two-step cycle. The carbonaceous material is reacted with bromine and water at about 250°C to form an aqueous solution of hydrobromic acid and CO_2. The aqueous hydrobromic acid solution is then electrolyzed to form hydrogen and bromine. The bromine is returned to the first step of the process. The overall reaction is thus:

$$C_6H_{10}O_5 \text{ (biomass)} + 7\ H_2O \longrightarrow 12\ H_2 + 6\ CO_2$$

Laboratory tests show that biomass materials such as algae, feed lot manure, kelp, sugar cane, wood, and water hyacinth react with bromine at a practical rate at 250°C. The hydrogen bromide yields from laboratory bromination reaction tests with these feedstocks indicate expected hydrogen yields of from 48,000 to 60,000 standard cubic feet of H_2 per ton of biomass feedstock (dry, ash-free basis). The process is particularly amenable to materials with high water content since the water requirement corresponds to a feedstock with approximately 44% water and 56% organic solids content for the bromination reaction.

Experimental data at temperatures up to 150°C indicated, upon extrapolation, that the electrolysis of concentrated HBr solutions (~45 wt % HBr) can be carried out at about 0.45 volt in the range of 250 to 300°C at a current density of 200 A/ft^2. This is approximately one-fifth the voltage required for the electrolysis of water. The theoretical

thermal energy conversion efficiency, i.e.,

$$\eta = \frac{\Delta H^{o}_{298}(H_2O, \text{ liquid}) \text{ kcal/mol } H_2}{Q(\text{kcal/mol } H_2)} \times 100$$

[where ΔH^{o}_{298} is the heat of combustion of one mole of H_2 with oxygen to form liquid water (68.3 kcal/mol) and Q is the total amount of energy input into the process to form 1 g-mol of hydrogen] of the process has been calculated to be about 67% using cellulose as a typical feedstock. If consideration is given to operation of the electrolysis cell under process conditions, an overall efficiency of about 59% is estimated. This efficiency does not take into account losses such as pumping power, heat losses, and the preparation and handling of feedstock, etc.

The process shows promise in the production of hydrogen primarily because of its high potential efficiency and its applicability to a broad range of feedstocks, particularly those with high water content.

FEASIBILITY STUDY ON THE PORSHE (PLAN OF OCEAN RAFT SYSTEM FOR HYDROGEN ECONOMY)

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EXTENDED ABSTRACT

INTRODUCTION

The grand project PORSHE (Plan of Ocean Raft System for Hydrogen Economy) is a system-concept combining ocean, solar light and hydrogen energy which would provide inexhaustible and energitic fuel and/or valuable chemical substances, coping with possible stagnation of the petroleum supply. The concept has been proposed by Ohta at THEME conference in 1974 and a research group named PORSHE System Society has been organized in Japan last year by scientists, engineers and economists of Universities, govermental institutes and companies for the purpose of the feasibility study.

The time schedule of the PORSHE has five phases, the first phase, 1978-1980, is the feasibility investigation period mainly by literatures and theoretical analysis, the second phase, 1981-1984, is manufacturing and control study period of a model raft (30m X 30m), the third phase, 1985-1987, is the application period of PORSHE to an actual ocean region. However, the first practical raft which has the scale of 1 km X 1km will equips with solar collector, heat storage vessels, turbine generator (50 MW) and the marine products factory. This may be called a proto type PORSHE Kombinat without hydrogen utilization. The sites in the feasibility study are Palau and/or Marshall islands. The fouth phase,1988-1997, is the period of construction and operation of a few rafts on the public midocean which produces ammonia, nickel,copper,cobalt,manganese, etc., from the submarine manganese balls, and heavy water as a biproduct of the electrolytic hydrogen production. This is the concept of PORSHE Kombinat.

OPTIMUM DESIGN OF SOLAR COLLECTOR

In the feasibility study on the PORSHE, we are tasked of developing some key technologies essential to the PORSHE. One of them is a solar collection system which is equipped to a fluctuating raft floating on the ocean. The present first report comprises the design of an effective stable collection system. Considering the collector system composed of a parabolic linear mirror and a focal line pipe, the conventional control for the solar tracking is done by moving one of the mirror and the pipe, while another is fixed on the base. However, this needs a lot of energy if applied to the PORSHE case.

New method invented by us is to separate the collection system, the both of the mirror and the pipe, from the base, then it is subjected to the conventional tracking.
The jogging force from the base to the system is decomposed into the translational, pitching and rolling forces. The first is of no effect to the solar collection. The structure of the raft is designed so as to give only negligible effect of pitching upon the collector system.
Thus the force acting upon the axis of the parabolic mirror, which is fixed with the focal line pipe, is only a torque around the axis. A torque sensor (e.g. CdS sensor) will pick up this torque and send out an electronic signal (the direction and the magnitude) to a control system which makes and transmits a counterbalancing torque to the collector axis after a short period.
This period has a limit of the shortest time which is determined by the mass and the structure of the raft and the buoyancy. One of the factors which determine the scale of the raft is due to this period.

Another distinguished character of our control system is a use of the " optomechatronics ". The posture of the collector system setting free from the base is controlled after the reference system which can perceive the direction of incident solar light by electronic way. When the direction goes to awrong way (no focusing) an electronic signal yields which is transmitted to a servomotors. These motors cooperatively control mechanically the posture of the collector.

The optomechatronical diagrams, circuits as well as the mathematical analysis will be presented.

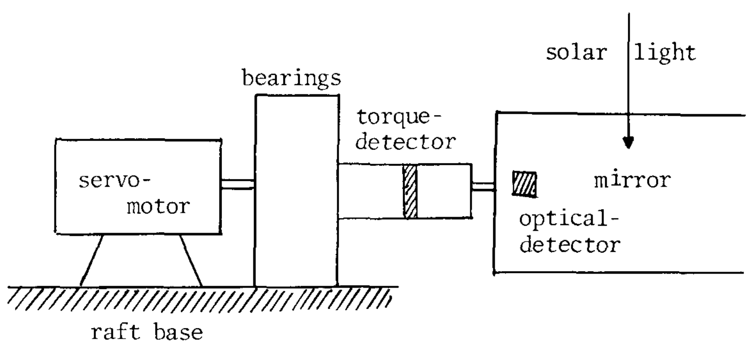

Fig. 1. Diagram of collector control system.

BIOLOGICALLY-ASSISTED HYDROGEN PRODUCTION: ATTEMPTS AT OPTIMIZING THE USE OF POLYMERIC VIOLOGEN MEDIATORS IN A BIOREACTOR BASED ON THE HYDROGENASE-CATALYZED DECOMPOSITION OF DITHIONITE

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EXTENDED ABSTRACT

INTRODUCTION

The enzyme, hydrogenase, when provided with the right conditions, can catalyze the breakdown of a reducing reagent with the concomitant production of hydrogen. For example, hydrogen can be produced by using the reducing agent sodium dithionite along with the enzyme and a viologen mediator (e.g. N, N'-dialkyl-4,4'-dipyridine). As a first stage in testing the feasibility of using systems containing this enzyme-mediator complex for the large-scale production of hydrogen, to be used either directly or indirectly (e.g. in methane production), we have begun the investigation of the use of hydrogenase coupled with polymeric viologen mediators. The use of polymeric viologen mediators would allow the construction of a bioreactor in which the enzyme and viologen mediator could be trapped. Dithionite pumped into such a system could be decomposed and waste products removed without loss of the enzyme or viologen mediator. The present communication will deal with the scale-up of a small bioreactor in which it was shown that the hydrogenase enzyme from *Clostridium pasteurianum* could be effectively coupled with several polymeric viologen mediators [1,2].

RESULTS

A. Optimization of Reaction Conditions. Our initial results indicated that the polymeric viologen mediators were as effective as the monomeric materials since they were more strongly bound to the enzyme [Km(app) increased] even though the maximum rate at which they catalyzed the reaction fell (Vmax decreased) [2]. The experiments we have subsequently carried out have been aimed at optimizing some of the parameters which could affect the efficiency of the operation of the bioreactor.

Before proceedings directly with the scale-up of the small, analytical bioreactor we have examined the use of whole cells vs. cell-free extracts, the preparation and use of cell-free extracts, as well as pH effects, dithionite concentration, salt concentration, surfactants, metal chelators and polymer concentration on the reaction.

B. Bioreactor Scale-up. Using the results we obtained from the analytical bioreactor we have scaled-up the process. The simplest scale-up, in which no waste removal and hydrogen production monitored manometrically, has been tried. The results from this ten fold scale-up will be presented along with some of our attempts to incorporate a waste-removal system into the process.

ACKNOWLEDGEMENTS

We wish to acknowledge valuable discussions with Dr. C.S. Chuaqui and Dr. K.R. Lynn.

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FIXED SITE HYDROGEN STORAGE: I. APPLICATIONS IMPACT*

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EXTENDED ABSTRACT

For hydrogen to play an important role in our energy future, all aspects of its usage scenario must be examined and understood. Certainly hydrogen production, transport, and end use are crucial areas for investigation, but what of storage? Widespread utilization of hydrogen may depend on the ability to store appreciable quantities to smooth mismatches between supply and demand. Storage of hydrogen may present special materials challenges due to hydrogen embrittlement phenomena and hydrogen's low heat content, which may lead to different trade-offs in storage design and performance than occur with natural gas. The necessity, viability and preliminary economics of bulk hydrogen storage are examined in this paper.

It has been assumed in this work that (1) hydrogen will be plentiful and available in all regions of the country; (2) the widest possible usage of hydrogen will be as a substantial replacement for natural gas in heating and electrical generation applications by distribution through existing natural gas pipelines and/or a similar pipeline system. Feedstock applications are also examined.

Storage of hydrogen (as with any fuel) will only be desirable if there are mismatches between production, distribution and usage rates. While this is true for any energy commodity, it is especially true for hydrogen, as it is neither a source of energy nor a necessary element in any envisioned energy economy. However, it may be an attractive medium of energy transport, distribution, end-use, etc. Hydrogen will be produced as a gas. Storage of gaseous fuels is usually unattractive; however, there may be instances when the storage of hydrogen would be beneficial

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and perhaps necessary. Consider the examples of oil or natural gas--these are produced at a constant rate, not at the convenience of a utility company as hydrogen might. It may be cheaper to transmit hydrogen at the maximum production rate, rather than to store it to smooth the flow rate. Alternatively it might be better to adjust the production rate to match the instantaneous transmission capacity. At any rate, avoidance of storage at the production site may be a viable possibility. It may even be possible to avoid storage of hydrogen at a distribution site by adjusting production rates to match the actual or predicted consumption rates. This concept of storage avoidance is not an attempt to skirt the issue but rather to get to the heart of the matter; hydrogen storage is expensive in any form (as is the storage of any gas), and industry will avoid its storage whenever economically or operationally possible. The necessity of hydrogen storage is herein examined by investigating likely sources and patterns of hydrogen production, distribution limitations and end-use consumption scenarios. To determine the needs and characteristics of hydrogen storage, the hydrogen energy cycle was broken into three sectors: production, distribution, and end use. In each of these sectors storage of hydrogen may be beneficial towards smooth and economical operation.

Hydrogen storage at constant production rate sites will not be needed (as there is no advantage to storing at all). Variable production rate locations (such as solar powered conversion plants) present a slightly different picture. Here a tradeoff exists between the cost of storage (to smooth transmission rates and hence lessen pipeline sizes and costs) versus the cost of the transmission line. For the solar hydrogen production case, storage is a more expensive option than simply oversizing the transmission lines to handle the maximum production rate. This result, of course, depends on the cost of storage and the cost and length of the transmission line, but nonetheless is quite broadly applicable. Unless extremely inexpensive storage is available (less than 100$/MBTU, 1972 dollars) or the length of the line is extremely long (say, more than 100 miles), storage is not the preferred option. The case of using off peak electricity for electrolysis is very similar to the solar case and for similar reasons storage is not attractive here either.

Hydrogen storage is most important and beneficial at distribution sites. This storage will be seasonal in nature (as natural gas storage is used currently). Even accounting for hydrogen's lower heating value (with respect to natural gas) the current underground natural gas storage facilities would provide almost all of the seasonal storage requirements envisioned. (Further, the amount of underground natural gas storage in the U.S. continues to increase while the consumption of gaseous fuels is decreasing.) Should this or similar storage not be acceptable for hydrogen service, the next best alternative may be above ground constructed vessels in the 1000 $/MBTU range. Since currently 7×10^9 MBTU of natural gas storage is used, a rough estimate of the cost of above ground hydrogen storage would be $7x10^{12}$ (seven trillion) dollars. This would probably be unacceptable to both hydrogen utilities and their customers. Hence effort should be put into assuring the viability of inexpensive storage, such as conversion of current natural gas storage facilities to hydrogen service.

Storage at the end use point is not really an issue. In a postulated scenario of widespread hydrogen usage, hydrogen will be available on demand from distribution and delivery networks as natural gas now is. Residential users will almost never be interrupted and industrial and commercial users will prefer oil as a back-up heat source rather than expensive hydrogen storage. Thus storage at the end-use point will rarely be required.

In summary then, the most pressing need for hydrogen storage is not at the production point (even for intermittent production) or the end use point, but rather at distribution locations. This is consistent with current natural gas practice. Conversion of natural gas storage to hydrogen service may well provide for storage at the distribution point.

HYDROGEN UTILIZATION IN DIESEL ENGINES

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ABSTRACT

In addition to energy crisis, increasing pressure is being placed on all concerned in research and industry to control combustion engine emissions to reduce atmospheric pollution. Hydrogen is the most potential contender to meet both the challenges and can be widely used as a fuel to replace petroleum products in the future, not only in mobile power sources, but even as domestic fuel. In this investigation, efforts were made to utilize hydrogen as auxiliary fuel in single cylinder diesel engines. Hydrogen from high pressure cylinders was introduced into the intake manifold of the engine and the quantity of injected fuel was controlled by means of a governor. The engines were operated at various loads with different proportions of hydrogen in total fuel quantity. It was possible to supply a maximum of 30 percent of energy input through hydrogen when the engine was operating at full load. At this load, hydrogen introduction increased the thermal efficiency of the engine, while at part loads, with increasing proportions it reduced the thermal efficiency. At any load, with increasing proportions of hydrogen, the ignition delay of injected fuel decreased slightly as expected; the peak cycle pressure increased indicating the rapidity of combustion and the rate of pressure rise was not very much affected.

With hydrogen introduction, the hydrocarbons in the exhaust were reduced, as expected. The reduction in exhaust nitric oxide concentration, though observed, was not very significant.

Unsteady operation due to incipient knocking indicated the upper limit to which the proportion of hydrogen could be increased. Charge dilution methods, intake manifold water introduction and exhaust gas recirculation, were tried to increase the proportion of hydrogen in total fuel consumption. Intake manifold water introduction was observed to be more effictive of the two by which the hydrogen proportion in the total energy input could be raised to 50 percent. Hydrogen supplementation with intake manifold water introduction has permitted the operation of engine at full load with reduced exhaust nitric oxide emissions and no penalty on thermal efficiency.

Closed vessel explosions were conducted to study the effect of adding hydrogen to hydrocarbon-air mixtures on the flame velocities. Flame velocities were measured in hydrogen-hydrocarbon-air mixtures of different proportions. It was observed that with increasing proportions of hydrogen, the flame velocity in hydrocarbon-air mixture increases.

SESSION 2F

ECONOMICS AND POLICY II

INTERNATIONAL ENERGY SUPPLIES AND DEMANDS: A LONG-TERM PERSPECTIVE

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EXTENDED ABSTRACT

This report begins by reviewing a series of recent projections of international energy supplies and demands. These international analyses are focused upon oil -- which has much lower transport costs than competing energy sources. The typical procedure is to postulate an international oil price trajectory and rates of GNP growth within each country or region, and then to deduce the oil demands of the importing nations. These demands are matched against the supplies that are likely to be forthcoming from OPEC and other major producers -- taking account of the geological resource base, proven reserves and announced production policies. When each of the national analyses are conducted independently, there may be logical inconsistencies -- hence a potential gap between international supplies and demands.

Virtually all of the official or semi-official studies published since 1977 have projected the emergence of a supply-demand gap at some point during the 1980's. That is, it would be <u>in</u>consistent for the importing nations' GNP to grow at their post-World War II rates and also for OPEC to maintain production ceilings and constant energy prices. Either GNP will have to grow at slower rates, or production must be expanded, or prices will have to rise still further.

Price increases are highly unpopular, and they lead to "windfall" profits for oil and gas producers. However, this may be the least <u>un</u>satisfactory way to deal with the international energy situation. Among professional US analysts, there is a substantial degree of consensus on the proposition that: "Higher energy costs cannot be avoided, but can be contained by letting prices rise to reflect them." Price increases provide the necessary economic incentive for increased supplies from high-cost sources: nuclear energy, shale oil, coal-based synthetic fuels and solar energy. At the same time, higher prices provide a more effective long-term incentive to conservation than moral suasion or government regulation.

These general ideas are illustrated through a series of numerical projections for the USA, employing a model nicknamed ETA-MACRO. This model allows for: energy-economy interactions, cost-effective conservation and interfuel substitution between electric and nonelectric energy. The calculations are based upon a less optimistic view of synthetic fuels and of solar

technologies than in several of the Carter Administration's recent reports. With synfuels, solar and nuclear energy -- and with realistically reduced projections of demand growth -- there is a reasonable prospect that the US could meet an international commitment to limit its oil and gas imports.

US import reductions could be achieved directly through the market mechanism, without tariffs or quota limitations. For this to happen, however, the international price of oil would have to be doubled once again (in constant dollar terms) by the year 2000. A policy of gradual OPEC oil price increases would facilitate the transition away from oil, and could serve the long-run interests of both the producing and consuming nations.

ECONOMIC EFFECTS OF INCREASED PENETRATION OF NEW ENERGY TECHNOLOGIES

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EXTENDED ABSTRACT

This paper presents an analysis of the economic effects of increases in the penetration of solar energy and of other new technology sources of energy. A Base Case energy and economic projection for the period until 2000 is first developed, assuming only a low degree of solar penetration. Two different projections are then developed by increasing the solar penetration levels relative to the Base Case. The differences between the economic structure and performance in the Base Case and in the moderate and high solar cases are therefore due entirely to the direct and indirect effects of the change in energy conditions. The analysis of these differences permits the macroeconomic consequences of increasing solar penetration to be assessed.

The differences in energy supply conditions can be summarized in terms of the level and composition of new source supply. In particular, the three different penetration cases for solar and biomass in 2000 are: 5.4 quadrillion Btu in the low penetration Base Case, 10.7 quads in the moderate penetration case and 21.8 quads for high penetration. (The basic information for these new technology levels is taken from the 1979 scenarios in the National Plan to Accelerate Commercialization of Solar Energy, NPAC). The capital and other costs of these new technology energy sources are taken from best current estimates and include allowance for future cost reductions resulting from increased experience with solar supply and with technology improvements.

Increased solar penetration requires considerable quantities of additional economic inputs, in particular inputs of capital. By 2000, the total capital stock required to provide the direct solar, solar electric and other new technology energy supply is considerable: \$(1972) 50 billion in the low penetration case and \$(1972) 136 bn and \$(1972) 276 bn in the moderate and high penetration cases. These capital requirements correspond to 0.8%, 2.2% and 4.6% of total U.S. capital stock in the three cases. When account is taken of the net capital requirements, particularly after allowing for conventional capital made unnecessary for the new supply, the capital demands are somewhat more modest--\$(1972) 100 bn in the moderate case and \$(1972) 172 bn in the high penetration case, corresponding to 1.6% and 2.8%, respectively, of total capital--but they still account for a sizeable fraction of total capital stock.

These capital changes are brought about by redirection of investment within the economy. These investment requirements peak during the 1990's at an average, for solar supply, of \$(1972) 4 bn annually in the low penetration cases and \$(1972) 17 bn and \$(1972) 35 bn in the moderate and high cases,

respectively. Total gross investment in the new technology supply sources during whole forecast period, i.e., both 1980's and 1990's, averages 1.3%, 3.3% and 7.0%, for the three levels of penetration respectively, of total investment in the economy. Even when allowance is made for the conventional energy investment displaced, the net investment requirements are still substantial--2.7% of total investment in the moderate case and 5.1% in the high penetration case. Further, the investment requirements peak in the 1990's: during this decade, the gross investment requirements of new technology energy sources correspond to 5.0% of total investment in the moderate penetration case and 9.9% in the high case. It is likely that such requirements can be accomodated within the capital markets but they are sufficiently large, and may be compounded by heavy investment requirements elsewhere in the energy system, that they will bid up interest rates and divert substantial volumes of investible funds away from the nonenergy part of the economy.

Increased solar penetration also has significant impacts on the level and growth of economic activity. The increased capital and other inputs directed towards the energy system result in reduced inputs being available to the nonenergy part of the economy and this, in turn, results in slower growth of capacity and productivity. Therefore, real GNP growth in the moderate and high solar penetration cases is slower than in the low solar Base Case. Correspondingly, real income and output is, in every future year, lower than it would have been in the absence of increased use of solar energy.

These impacts are, in relative terms, sustainable--economic growth continues and material living standards continue to increase. Real GNP growth in the moderate penetration case is not affected prior to 1990 then, in the 1990's is slowed by only 0.1 percentage points annually, from 2.8% in the Base Case to 2.7%. In the high penetration case the slowdown is more noticeable, being 0.1 percentage point in the 1980's and 0.2 points (from 2.8% to 2.6%) in the 1990's. By 2000, these correspond to real GNP levels being 0.9% lower than the Base Case for moderate penetration and 2.9% lower for high penetration.

Although economic growth continues even with an expanded solar energy program, the costs imposed by widespread use of solar and other new technologies are nonetheless substantial. The total loss in real GNP between 1980 and 2000 amounts to $(1972) 86 bn for the moderate case and $(1972) 413 bn in the high penetration case. The present values (to 1980 at a 5% real discount rate) of these losses are $(1972) 37 bn and $(1972) 202 bn, respectively. These correspond to lump sum taxes of $667 and $3648, in the moderate and high penetration cases, for every household in the U.S. in 1980. On any of these measures, the aggregate economic costs of a new technology energy program can be very significant.

The economic conclusions are that a large scale solar energy program will have noticeable, and adverse, effects on the economy in terms of slower growth of incomes and output. The relative magnitude of these costs is such that economic growth continues at positive rates, although rates somewhat below those projected without the solar program. The absolute magnitude of the costs, however, is substantial. This implies that a large scale solar program, particularly in the moderate penetration case, is sustainable but that it still involves significant economic costs. From a policy point of view, these costs must be weighed against the benefits from solar energy (in terms of reduced oil imports and greater security in energy supply and in terms of reduced environmental and health damage caused by production and use of fossil and nuclear fuels) in evaluating the overall attractiveness of a major solar energy program. A further policy conclusion is that the costs of solar energy are critical in determining its general economic impacts and that, at present costs, solar is sufficiently expensive that its introduction would have adverse economic effects. Considerable more development work, directed towards making new energy technologies more cost-effective, is required before the widespread introduction of solar and other new technology energy supplies can be accomplished without a substantial economic penalty.

THE ASSIMILATION OF NEW TECHNOLOGY: ECONOMIC VS TECHNOLOGICAL FEASIBILITY

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EXTENDED ABSTRACT

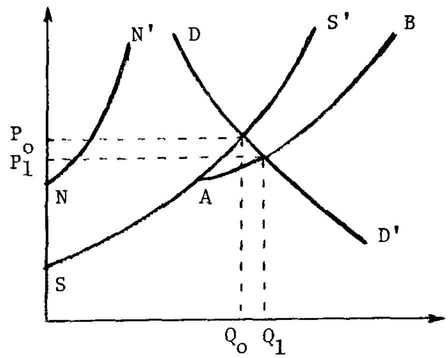
INTRODUCTION

Recent events have led to an upsurge in interest in the use of alternative technologies to provide energy. One approach concentrates on the development of alternative forms of energy (e.g., breeder reactors and solar collectors). Another concentrates on the use of non-conventional technology to extract hydrocarbon fuels (e.g., gasification of coal, massive hydrolic fracturing of gas fields of low permeability, and nuclear in situ retorting to extract oil from oil shale). It is with the latter approach that this paper is primarily concerned.

The great majority of the research has been concerned with technological rather than economic feasibility. These studies have generally assumed that, for some unspecified reason, quantity supplied of the energy resource will be less than quantity demanded in some future period. After estimating this "gap", those using this approach then proceed to estimate the effect that the higher-priced nonconventional technology will have upon average price, assuming that price is solely determined by the cost of recovering, transporting, and distributing the resource. The conclusion of such studies is that the implementation of nonconventional technology will result in higher prices to the consumers. A fundamental error in logic in such an approach is that it fails to incorporate the effect of price.

THE EFFECT OF IMPLEMENTATION OF NONCONVENTIONAL TECHNOLOGY

In this section of the paper the question that will be addressed is the impact of the implementation of nonconventional extraction technology on the price and output of the energy resource. Our analysis may be summarized in the following figure. In this, DD' represents the market demand for the resource and SS' the (long-run) supply curve employing only conventional technology. Now, let NN' represent the supply curve for nonconventional production. Embodied in the construction of this figure are two assumptions. First, we assume that there exist deposits for which the cost of conventional extraction would exceed the cost of nonconventional extraction (e.g., oil shale). Hence, we assume the two



supply curves to be independent of one another. Second, the fact that the nonconventional supply curve lies everywhere above conventional supply reflects our assumption that nonconventional extraction is more expensive. Since we consider a competitive market, the total supply function is simply the horizontal summation of the two supply curves and may be represented as SAB.

With no nonconventional production and with free markets, the intersection of market demand, DD', and conventional supply, SS', determines an equilibrium price of P_o and an output of Q_o. However, if the total supply function is employed, the equilibrium price falls to P_1 and output rises to Q_1. In a freely functioning market, <u>the use of nonconventional technology will lower rather than raise the price the consumers will pay for the energy resource</u>. In the long run, the increase in output from nonconventional production will depress price, unless there exists an externally induced shortage (possibly the result of a governmental ceiling price below equilibrium).

THE DEMAND FOR NONCONVENTIONAL TECHNOLOGY

Since our analysis concentrates on the use of nonconventional technology in the extraction of hydrocarbon fuels, the inherently dynamic nature of this process must be incorporated. That is, an increase in the current rate of extraction increases the cost of extracting a given amount of the resource in future periods. Hence, the objective of the firm must be the maximization of present value (or net worth),

$$PV = \sum_{t=0}^{H} \left(\frac{1}{1+r}\right)^t [R_t - C_t(q_t, q_{t-1}, \ldots, q_0, N_t, N_{t-1}, \ldots, N_0) - F_t - P_{N_t} N_t - G(N_t) - T_t]$$

where the variables are defined as follows. H is the firm's time horizon. r is the relevant discount rate. R_t is revenue net of royality payments in period t. C_t is the operating cost in period t. F_t is the fixed cost in period t. $G(N_t)$ represents any additional costs due to the implementation of the nonconventional technology. P_N is the price of the nonconventional technology. T_t is the federal income tax in period t defined to be $A[R_t-C_t-G(N_t)-P_N N_t-DR_t-M_t]$ where A is the rate of taxation, D is the depletion rate, and M_t is allowable depreciation.

In the context of our specification, the following relations are assumed in the cost function: (1) An increase in the current rate of extraction increases total and marginal cost in the current period and increases total cost in future periods ($\partial C_t/\partial q_t>0$, $\partial^2 C_t/\partial q_t{}^2>0$, $\partial C_{t+i}/\partial q_t>0$, $\partial^2 C_{t+i}/\partial q_{t+i}\partial q_t\geq 0$). (2) An increase in the level of usage of nonconventional technology may lower total cost in the current and future periods; but there would exist non-increasing returns ($\partial C_t/\partial N_t\leq 0$, $\partial C_{t+i}/\partial N_t\leq 0$, $\partial^2 C_t/\partial N_t^2\geq 0$, $\partial^2 C_{t+i}/\partial N_{t+i}\partial N_t\geq 0$). Further, the implementation of nonconventional technology would not increase the marginal cost of extraction ($\partial^2 C_t/\partial q_t \partial N_t\leq 0$, $\partial^2 C_{t+i}/\partial q_{t+i}\partial N_t\leq 0$).

The firm maximizes present value through its selection of the rate of extraction, q, and the level of usage of nonconventional technology, N. Mathematically, the necessary conditions are

$$\left(\frac{1}{1+r}\right)^t (1-L)(1-A(1-D))P_t = \left(\frac{1}{1+r}\right)^t (1-A)\partial C_t/\partial q_t + (1-A)\sum_{t+1}^{H}\left(\frac{1}{1+r}\right)^i \partial C_i/\partial q_t$$

$$\left(\frac{1}{1+r}\right)^t (P_N+\partial G_t/\partial N_t) = \left(\frac{1}{1+r}\right)^t \partial C_t/\partial N_t + \sum_{t+1}^{H}\left(\frac{1}{1+r}\right)^i \partial C_i/\partial N_t.$$

The first equation indicates that present value is maximized when net marginal revenue in the period is equal to current marginal cost plus the discounted effect of current extraction on future cost. The second indicates that the optimal level of usage of the nonconventional technology is that at which its discounted cost is equal to the discounted marginal reductions in cost in the current and future periods.

After employing some simplifying assumptions that are consistent with the general assumptions presented earlier, the comparative statics properties were examined. With respect to output, an increase in the rate of increase in the price of the energy resource, the rate of percentage depletion, or the discount rate would increase the current rate of extraction, while increases in the rate of income taxation or the rate of increase in operating costs would reduce it. With respect to nonconventional technology, it was found that an increase in either the rate of increase of operating costs or the discount rate would increase the level of usage, while an increase in the price of the nonconventional technology would reduce usage.

A PROBABILISTIC COMPARISON OF COAL & NUCLEAR POWER COSTS

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EXTENDED ABSTRACT

INTRODUCTION

A recent report from the Nuclear Regulatory Commission [1] projects the costs of electricity from nuclear and coal-fired power plants coming into operation in the late 1980s; it concludes that nuclear power will be from about 0% to 20% cheaper per KWH depending on geographic location in the US. Another recent study, by Komanoff Energy Associates [2], concludes that nuclear generated electricity will cost about 50% more than coal. Unfortunately such divergence in conclusions is not untypical in the analysis of energy systems, and the situation is even worse for less developed technologies. Some of these differences may be due to unavoidable uncertainties in technical forecasting which policy analysts are generally willing to acknowledge. Presumably the rest of the discrepancy is due to actual differences of opinion about the future values of input quantities and about the appropriateness of different methodologies (such as whether to include taxes as a real cost).

A problem with analyses that use conventional deterministic methods is that it is difficult to distinguish conflict of opinion from technical uncertainty, and hence to evaluate the intehded significance of the results. Since we cannot hope for certainty, we would at least like to be able to answer questions like "On the best available information what is the probability that nuclear power is cheaper than coal?". This study is intended to demonstrate the feasibility and benefits of incorporating uncertainty explicitly in this sort of comparative cost analysis (see [3] for another example).

DECISION FORMULATION

The decision to be considered is that facing a hypothetical power company which forecasts a need for increased base-load electrical capacity in 1990. It assumes that coal-fired plant with sulfur scrubber and light water nuclear reactor are the dominating options, and that the choice of technology must be made in 1980. The comparison is in terms of the cost of electricity per KWH in 1990, using an average levelized over the life of the plant. It compares plant configurations which are expected to generate equivalent average energy (not necessarily of equal designed capacity, depending on relative capacity factors).

The quantities considered include capital costs, capacity factors, fuel costs, pollution control costs, nuclear waste disposal and decommissioning costs, rate of return on capital and discount rate. Following [1], the analysis takes into account regional variations in construction costs and coal costs within the US. It does not currently include health hazards and environmental costs except to the limited extent that they are internalized in the cost of pollution control devices, safety systems and insurance.

SENSITIVITY TO UNCERTAINTY AND DISAGREEMENT

The first part consists of a systematic sensitivity analysis of the assumptions used by the two studies mentioned above to establish

(a) which quantities are most critical to the cost differences between coal and nuclear, according to each study,

(b) which uncertainties are most critical to their conclusions, using a credible range for each quantity as an initial representation of its uncertainty,

(c) which disagreements in methodology and assumed values of the quantities are most critical to the differences between the conclusions of the two studies.

PROBABILISTIC ANALYSIS

In the second part probability distributions are assessed for those quantities determined as most critical in the first part, and the analysis is repeated in probabilistic form. The opinions of a representative range of experts are elicited on the future values of these quantities and they are encoded as subjective probability distributions. Disagreement between experts is treated as additional uncertainty and their separate assessments are combined into a single distribution for each quantity. The analysis is performed by Monte Carlo simulation using DEMOS (Decision Modeling System) which is an interactive computer language for aiding decision analysis [4].

CONCLUSIONS

The primary results are a set of probability distributions on the relative cost per KWH of the two energy sources. Preliminary analyses suggest a probability of 65% to 85% that coal is cheaper than nuclear power under the specified conditions, depending on particular plant site and configuration. This may be modified as further expert assessments are incorporated, but in any case it is clear that the uncertainties are of significant size relative to the expected differences between the alternatives.

This is supplemented by a comparison of the contributions to the overall uncertainty of the various sources of uncertainty and disagreement in the data. Based on an estimate of the rate of investment in the construction of new baseload capacity, it is also possible to compute upper bounds on the value of more precise information on those quantities that are potentially researchable. These results may be useful to policy makers to help decide which issues should have most attention focused upon them in future studies.

This paper presents some specific comparisons of coal and nuclear costs with explicit consideration of current uncertainties in expert opinion, but it is primarily intended as a general demonstration of the practicality and usefulness of probabilistic methods in choosing between energy technologies and in planning research. Future work should extend the analysis to include environmental costs and health hazards and comparisons with renewable energy sources.

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NOTE

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A COMPARISON OF THE INCENTIVES USED TO STIMULATE ENERGY PRODUCTION BETWEEN THE UNITED STATES AND JAPAN

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EXTENDED ABSTRACT

INTRODUCTION

A comparison of the actions of the U.S. and Japanese governments directed toward energy production is presented in this paper. The comparison starts by defining what is to be considered a government incentive. In the next stage the incentives are quantified and the qualifying assumptions are stated. Finally, a comparison between the U.S. and Japanese incentives used to stimulate energy production or access is presented. This comparison fully considers and comments on the different energy situations of each country.

INCENTIVES TYPES

Developing an understanding of what a government incentive is and how it is recognized was a major task at the outset of this research effort. Government actions are first split up into eight distinct types of action or categories. These are as follows:

1. The creation or prohibition of organizations that carry out actions set by policy or charter
2. The levying of a tax or the exemption or reduction of an existing tax
3. Collection of fees for the delivery of a governmental service or good not directly related to the cost of providing that good or serivce
4. Actions in which the Federal Government disburses money without receiving anything in return, directly or immediately
5. Demands or requirements made by government, backed by criminal or civil sanctions
6. Assistance or benefit traditionally provided by the government through a nongovernmental entity without direct charge (i.e., regulating interstate and foreign commerce and providing inland waterways)
7. Nontraditional government services, including activities such as exploration, research, development, and demonstration
8. Market activity, or government involvement in a market under conditions similar to those faced by nongovernmental producers or consumers.

Major government actions were categorized and examined from economic, legal, organizational and political viewpoints to choose those considered incentives. Then, both quantifiable and non-quantifiable incentives were analyzed for the U.S. and Japan. In practice, the cost of creating or prohibiting organizations cannot be accurately determined and the amount of fees collected is negligable. Therefore these two categories do not appear in the tables but they are included here for completeness.

INCENTIVES TO MAJOR ENERGY FORMS

The major energy sources (nuclear, hydro, coal, oil and gas) are analyzed along their trjectories from exploration to waste management. The study considers actions in the U.S. that date from as far back as 1918. The Japanese study considers actions dating from the reconstruction after WWII. Summarized comparisons of government actions on a historical basis are presented in Tables 1 and 2.

TABLE 1

Historical Incentives to Energy Sources for the U.S. and Japan
(Billions of Dollars)

	United States (through 1977)		Japan (through 1976)	
Energy Form	Total	Percent	Total	Percent
Nuclear	18.0	8.3%	4.8	3.9%
Hydro	15.3	7.0%	12.1	9.7%
Coal	9.7	4.5%	8.4	6.8%
Oil	101.3	46.6%	98.6 (Oil and Gas)	79.6% (Oil and Gas)
Gas	16.5	7.6%		
Electricity	56.6	26.0%	-	-
Total	217.4	100.00%	123.9	100%

TABLE 2

Historical Incentives Allocated by Type of Government Action for the U.S. and Japan. (Billions of Dollars)

Government Action	United States (through 1977) Total	Percent	Japan (through 1976) Total	Percent
Taxation	103.6	-47.7%	.2 -54.3	.2% -43.8%
Disbursements	1.1	0.5%	4.9	4.0%
Requirements	43.8	20.1%	1.6	1.3%
Traditional Services	8.8	4.0%	119.2	96.2%
Non-Traditional Services	19.6	9.0%	3.2	2.6%
Market Activity	40.6	18.7%	49.0	39.5%
Total	217.42	100	178.2	143.8
Net Total	217.42	100	123.9	100%

NOTE: Tables 1 and 2 use a 1976 Yen conversion rate of 297.

It is interesting to note that the historical incentives for each energy form are similar whereas the allocations by government actions are quite different. In addition to the quantifiable incentives presented in the above tables there have been several laws and policy decisions enacted that have required minimal outlays yet have had a major impact on energy production. Examples of these include the Price-Anderson Act, the Connally Hot Oil Act, the Interstate Oil Compact Act, the creation of the Atomic Energy Commission and other agencies in Japan.

The full paper deals with the major actions under-taken by the U.S. and Japanese Governments in more detail for each energy source.

When Do We Need the Alaska Highway Gas Pipeline?

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Abstract

Over the past ten years there have been various proposals to construct a pipeline across the Northwest Territories to Alaska to provide a method for transporting Alaskan natural gas to lower "48" states markets. Negotiations between the U.S. and Canadian government and native peoples have dealt with many issues and it is likely that if such a pipeline is built it will take a route along the Alaskan highway and there will be one or more spurs that would bring Canadian Frontier gas to Canadian markets. This paper surveys and analyses several U.S. and Canadian studies concerning the economic potential and need for this gas. These include Helliwell's dynamic simulation model from the Canadian viewpoint and an analysis using PIES from the U.S. viewpoint. These analyses and recent economic and political developments cast doubt that the pipeline is needed and will be built in the near term future.

FUTURE ENERGY OPTIONS FROM THE STANDPOINT OF A DEVELOPING COUNTRY

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EXTENDED ABSTRACT

INTRODUCTION

Lately a number of independent studies resulted in predictions of long range global energy demand at a level of about fifty TW years per year somewhere around the middle of the next century. These studies have considered possibilities of meeting this demand from different energy sources. They all agree that conventional energy sources, fossil fuels and nuclear fission convertors, could meet the demand only to the end of this century. After that, unconventional energy sources, fission and fusion breeders, solar and geothermal energy, have to make the balance at an increasing rate. The rate of introduction of unconventional energy sources would have to be very fast already in the first decades of the next century. This fact points out to several conclusions. First, no single source could be introduced that fast, only a mix could possibly do. Then, research and development and decision making process have to be such as to make ready adequate technologies soon enough. Finally, necessary capital has to be assured for the investments.

Although taking care of regional differences, mentioned studies were mainly concerned with the global aspects of the problem. In this paper an attempt is made of separating problems of developing regions, principal energy consumers in the future, from those of the most developed regions which are dominant energy consumers at the present. As a result, it comes out that in the next century problems of introducing unconventional energy sources in developing regions are much more severe.

UNCONVENTIONAL ENERGY SOURCES

Main characteristics and prospects of development of principal unconventional energy sources are shortly reviewed in the paper. Although corresponding technologies differ very much between each other they have certain features in common. None of these is ready for wide scale use as yet. Therefore, necessary research and development requires large funds and especially time. The time element is very important as most of these technologies have serious problems with the environment, resulting in long leading times for public acceptance, plant construction and market penetration. Also, a wide variety energy supply options are in principle possible for each of the unconventional energy sources. Solar energy is a typical example, with a variety of options available for the electricity, heat or fuel supply each. A wide variety of options tends to diffuse research and development efforts which rely on a limited amount of funds available.

Therefore, an efficient decision making process has to be employed, based on limited but reliable amount of information, and leading to optimum options in the shortest possible time. Finally, in all these technologies "fule" costs tend to be marginal and captial costs are dominant. Furthermore, these captial costs are substantially higher than those of conventional energy technologies. Thus, the availability of the investment captial is one of the most crucial issues.

ENERGY DEMAND AND SUPPLY IN DEVELOPING COUNTRIES

It is well known that at the present about one-quarter of the global population, *living in developed countries, consumes around 85% of the global* energy demand. It is also known, but perhaps insufficiently emphasized, that the high rate of increase of global energy demand in the future is mainly due to the high rate of population growth and the necessary increase of energy consumption per capita in developing countries. Somewhere in the first half of the next century the situation in global energy consumption will change in the sense that about 85% of the population living in the countries which are at the present in development will consume at least the same amount of energy as the population in the developed countries.

To accomplish this developing countries dispose with much less resources than the developed countries. As far as natural resources are concerned it is true that most of the oil is found in some of the developing countries as a principal source of income and partly because of a limited demand for expensive oil in the near future in developing countries the consumption of oil in developed countries will most probably be greater than in the developing countries all throughout this century. The principal fossil fuel resources are in coal, however, the 80% of these resources are believed to be in the developed countries. In fact it is expected that the coal will play a significant role in bridging the gap between the oil dominated energy economy of the present and the unconventional energy ec onomy of the future.

UNCONVENTIONAL ENERGY SOURCES AND DEVELOPING COUNTRIES

In the paper possibilities of meeting the energy demand in developing regions from conventional energy sources are discussed. As a result it comes out that the use of unconventional sources has to be made in these regions somewhat earlier than in the developing countries. What is much more important, the rate of increase of the unconventional energy capacity, and, moreover, its absolute value should be greater in developing than in developed countries. Thus, not only these countries have to rely more than developed countries on unconventional energy sources but also the major part of the capacity of these sources has to be installed in them. In other words developing countries have to become leaders in the use of the most advanced and the most expensive technology. How? This is the question.

As far as natural resources are concerned there seems to be no problem, at least developed and developing countries are in similar situation.

Unconventional energy is already being used in developing countries. Solar drying and water pumping, biogas production and other means have been successfully employed on a small scale. This is more or less satisfactory as a beginning and at this stage of the energy demand in these countries. Already at the beginning of the next century, however, large scale energy production will be needed. This implies different, more sophisticated and more expensive technologies of solar energy utilization as well as probably the use of fission and evan fusion breeders.

Raising of necessary financial means will be crucial but the other issues are also very important. The most advanced energy technologies are being developed in the industrialized countries at the present, where by far the most part of the funds for the research are being given. For a significant period of time developing countries have to rely on imported technology. However, there is a wide variety of possible options. Decision process has to rely on competent people, reliable information and modern means of analysis. These matters are discussed at some length in the paper.

No immediate solution of the problem is available as yet. However, the importance of these problems for the smooth development in the future requires that they are emphasized at this stage so that at least some solutions are attempted.

AN EVALUATION OF ALTERNATIVE ENERGY SOURCES FOR THE GUYANA ENERGY CRISIS

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EXTENDED ABSTRACT

INTRODUCTION

Guyana has no fossil fuels and therefore has to import the majority of its energy sources. This situation helped to create an economic crisis which has gotten worse with every increase in the price of oil by the OPEC countries. The price of exported raw materials has also declined over the years. While the price of imported manufactured goods has shown a great increase. In 1971, Guyana imported (US) $9 million worth of oil; this figure rose to (US) $78.7 million in 1978. It is expected that by the end of 1979, this figure will exceed (US) $100 million. Agriculture, mining and manufacture together contribute approximately 5% of the gross domestic product and also account for 80% of the total energy consumption of Guyana.

TABLE I [1] summarizes the generating capacity in Guyana. TABLE II gives a forecast of electrical energy utilization 1975-1995[2].

ALTERTIVE ENERGY SOURCES

The paper examines three energy sources for the economic development of Guyana viz.

(a) Hydropower
(b) Tidal Power
(c) Ocean Thermal Energy Conversion

Hydropower

The first feasibility studies as regards hydropower were conducted as early as 1919 in then British Guiana. Further studies were carried out in the early 1960's. This included a survey by the UNDP of oil potential hydroelectric sites with a potential of over 6 megawatts. As a result of these studies, the upper Mazaruni River, Mazaruni-Potaro District, was considered the most advantageous.

The main features of the proposed hydropower scheme are:

(1) a drain 43 meters high and 427 meters long at its credit
(2) a power station
(3) a power transmission corridor, approximately 320 kilometers long
(4) an access road 361 kilometers in length
(5) eventual production of 3,000 megawatts.

The estimated cost in 1976 was (US) $472 million. However, this figure was expected to exceed (US) $500 million. It is expected that realization of the scheme will see development of the hinterland with such industries as, an aluminium smelter and an ammonium nitrate fertilizer plant.

Work on the access road has been progressing steadily. An international seminar was held in Georgetown, Guyana, 4-8 October 1976, to examine the impact of the scheme on the environment. Such problems as human resettlement, health and ecology were examined. The work continues. Figs. 2,3 and 4 illustrate some details of the proposed hydro-electric installation.

Tidal Power

The other area seriously considered for the economic development of Guyana is tidal power. Tidal mills were widely used in the United Kingdom, India, France and Spain in the 11th century. The tidal mills (32-100kw) disappeared towards the end of the 19th century with the advent of cheap fossil fuels and hydro-electric.

The first tidal power plant to be built was at Rance, France, in 1966. The tides at Rance have an average range of 27 feet. The power station contains 24 units each rated at 10MW providing an annual production of 544 million kwh [3]. The U.S.S.R. has also built a 400 kw tidal power plant (1968) at Kislaya Bay, utilizing 11 feet tides with a bay area of 70 m^2. Recent studies have been conducted in the United States, Great Britain and India. Extensive studies have been conducted in the United States at Passamaquoddy Bay, Maine, Saint John River Power Project. The proposal is for a tidal power plant providing a million kilowatts of capacity in two 500 megawatt power plants with 50 units each.

Ocean Thermal Energy Conversion (OTEC)

The ideal for OTEC was first conveived in 1881, by a French physicist, Jacques d'Arsonval, for a heat engine to utilize the temperature difference between the top layer and bottom layers of the ocean. Tropical oceans are very favourable sites for solar seapower or OTEC, because of temperature differences of 20-23°C. No hurricanes threaten Guyana's coastal areas, although winds can gust up to 50 knots.

OTEC is attractive because of inexhaustible supplies for fuel, as well as, the non-pollution factor.

Important criteria for OTEC sites are:

(i) High thermal differences between the warm surface and the cold deep water.
(ii) Low-velocity currents.
(iii) Absence of storms.
(iv) Nearness to the market for the OTEC product.

The potential sites [7] for OTEC plants are located within 20° latitude north and south of the equator and along the routes of currents which carry warm waters away from the equator.

CONCLUSION

Of the three alternative energy sources considered in this paper, hydro-electricity will have to play an important role as a cheap source of power for major industrial projects to become a reality. Tidal power can play an important role by supplying power for the coastal areas and at the same time being a part of the sea-defense mechansim. This means that the Kingston power plant will play a supplementary role and so save foreign exchange used to purchase Bunker "C" fuel. OTEC cannot be seriously considered for some time to come.

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SESSION 3A

SOLAR COLLECTORS III

ABSTRACT

"Heat Transfer and Thermal Stress in
a Random Environment"

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Various solar collector devices have been designed in recent years for the purpose of harnessing solar energy. Many of these designs incorporate tubular heat exchangers with their outer surfaces exposed to the elements while a fluid courses through them. These tubes are usually constructed as layered cylinders consisting of several concentric layers of insulation and absorbtive, emissive and conductive materials. Because the mechanical and thermal properties of these materials are all different, thermal stresses develop at the interfaces. Such stresses may produce fatigue, delamination and possibly fracture of the tubes.

Solar radiation, ambient temperature and wind velocity which are the input variables for the problem are all random time series with continuously, but statistically, varying amplitudes and frequencies. As a consequence, heat transferred into the interior of the collector is also a random variable producing a time series of temperatures and stresses in the multilayer cylinder.

Hence the paper analyses heat transfer in a multilayer cylinder utilizing as input hourly observations of temperature, solar radiation and wind speed as recorded by the National Oceanic and Atmospheric Administration for various geographical locations in the U.S. The heat

balance relation on the surface of cylinder consider both absorbed and emitted radiation, as well as, convection and conduction. The one dimensional Fourier heat equation is then used to determine conductive heat transfer into the cylinder. A finite difference approach is used and axial symmetry is assumed.

Once the heat transfer relation and hence the temperature at every point in the cylinder is calculated a thermal stress analysis is performed and stresses and strains are calculated at all points. These stresses may produce random load fatigue in the tube. As a consequence a fatigue life for such a system can be calculated if a cumulative damage rule is assumed.

The paper also shows that insulation on the tube may be optimized to permit maximum irradiation and minimum reradiation.

THE DEVELOPMENT OF A FREEZE-TOLERANT SOLAR WATER HEATER USING CROSSLINKED POLYETHYLENE AS A MATERIAL OF CONSTRUCTION

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EXTENDED ABSTRACT

INTRODUCTION

The heating of water should become the first large direct use of solar energy that is cost-effective because the expensive solar collection equipment can be used every month of the year, and the desired temperature is so low that extraordinarily expensive collectors need not be used.

One important reason why solar water heaters are still uneconomically expensive is the problem of water freezing and bursting its tubes in the collector during winter nights. The usual solution to this problem is to use a non-freezing collector fluid and to transfer its heat to the water through a heat exchanger. The heat exchanger and the extra pump and controls on the collector fluid loop and the thermodynamic losses in the heat exchanger which require additional collector area form a substantial portion of the overall cost of a solar water heating system.

When the linear molecules of polyethylene are crosslinked into a three-dimensional network this material can no longer be melted, yet it retains strength and leathery toughness and corrosion resistance at temperatures far below the freezing point of water up to above the boiling point. Therefore, crosslinked polyethylene promises to be an excellent material of construction for a freeze-tolerant solar heater for water at typical domestic water pressures.

Crosslinked polyethylene is also much less expensive on a cents per cubic inch basis than other materials used in solar water heaters.

OBJECTIVE

The objective of the present investigation was to check the ability of crosslinked polyethylene tubes to absorb the strains of repeated freezing and thawing of water at typical domestic water pressures.

PROCEDURE AND RESULTS

Ten-foot tube specimens made from various crosslinked polyethylene formulations were filled with water at various pressures, and then placed into a deep freeze, then thawed and frozen again for 100 freeze-thaw cycles, or until the tube specimen failed. Tube diameters were measured before and after each freezing to determine how much distention the freezing caused, and how much permanent distention was caused by the strains of repeated freezings. Five tube specimens containing water at as high as 80 psi survived 100 freeze-thaw cycles. The permanent distentions of these five tubes ranged from 0.31% to 3.25%.

The following is a table of the test results of tubes that survived 100 freeze-thaw cycles:

TEST COIL NO.	1	8	9	10	12
Tubing OD - inches	.390	.385	.385	.333	.384
Wall of tube - inches	.049	.046	.043	.023	.040
Water pressure in tube psig	30	56	80	52	56
Hoop stress in tube wall psi	104	206	318	350	241
%Distention of tube diameter after 100 freeze-thaw cycles	0.45	0.31	1.22	0.37	3.25
Formulation of crosslinked polyethylene					
Polyethylene resin density g/cc	.927	.96	.96	.96	.933
Polyethylene resin melt index	2.17	3.0	3.0	3.0	2.33
Loading of GPF*phr**	20	40	40	20	40
Loading of antioxidant phr**	0.5	0.5	0.5	0.5	0.5
Loading of peroxide cross-linking agent phr**	2.5	1.5	4.0	1.5	1.5

* GPF is General Purpose Furnace Black

** phr is parts by weight per 100 parts by weight of resin

A flat plate collector was fabricated using as absorber surface a single 400 Ft. tube of carbon-black-reenforced crosslinked polyethylene in the form of a flat spiral coil, and this collector was tested for performance at the Los Alamos Scientific Laboratory. The performance test indicates that the absorbtivity of such a flat spiral coil to solar radiation is similar to typical black surfaces used on solar absorbers.

CONCLUSIONS AND RECOMMENDATIONS

Thus, it does seem very feasible that domestic water can be directly heated in a solar collector having an absorber made from crosslinked polyethylene, and that this collector can safely withstand at least 100 freeze-thaw cycles.

Since the single tube flat spiral coil collector design used in the present investigation had a high pressure drop, a more conventional collector design using parallel tubes with headers should be built and tested to determine whether the joints between a header and the tubes are as freeze-tolerant as are the tubes themselves.

Black Zn-dust pigmented solar selective coatings for solar photothermal conversion

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Abstract

Widespread utilisation of solar energy requires the development of a durable low cost, optically efficient solar selective coating. Solar selective surfaces in addition to having high absorptance and low thermal emittance must be stable at high operating temperatures and atmospheric corrosion resistant. At low operating temperature ($< 60^{o}C$) non-selective absorbers can serve the purpose but for driving a heat pump efficiently and cooling, requires higher operating temperature of about $120^{o}C$. The use of optically efficient solar selective absorbing coating is then necessary.

In the present study, selective black paint coatings have been prepared by coating reflective metal particles with a layer of selective black material. The coated particles were mixed in a binder and applied easily as a thin layer on to aluminium or galvanised iron sheet. Three selective black materials namely CuO, CuS and PbS + CuS have been deposited on zinc metal powder (325 mesh). These coatings unlike those of Telkes[1], cure at room temperature. The solar absorptance of the coatings is $\gtrsim$ 0.95 and emittance is $\lesssim$ 0.4. The thickness of the coatings was about 20 to 30 μm. The improvement in the collector efficiency which is the ratio of the temperature increase above the

temperature of the standard panel and the temperature increase of standard panel above the ambient temperature is estimated to be around 11 per cent.

Several authors (1-3) have investigated selective properties of solar selective paints. The selective paints were prepared by mixing a semiconductor powder e.g. PbS, Si, Ge CdTe, CdSe etc. with a infrared transparent binder material. The observed solar absorptance values were ranging from 0.83 to 0.96 for Si, Ge and PbS along with a thermal emissivity of 0.48 to 0.72. Telkes[1] has prepared CuS, CuO and CuS + PbS coated metal selective paints. These paints have absorptance of 0.95 but no emittance data have been reported. In the present investigations the cupric oxide coated zinc dust pigmented solar selective paint gives thermal emmitence as 0.42 which is lower than that of other paints. This process is a low cost for large scale application in solar photothermal conversion.

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ABSTRACT

PERFORMANCE COMPARISON OF FLAT PLATE COLLECTOR ABSORBER COATINGS UTILIZING NBS STANDARD 74-635 AND COLLECTOR PERFORMANCE METHODS

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In order to best evaluate the relative performance of conventional flat black and selective coatings for absorber plates in flat plate collector, a project was implemented to study several coatings under specified conditions.

Five coatings, 1) flat black, 2) black chrome, 3) NASA thermal paint (Z306 Polyurethane Coating, Lord Corp.), 4) carbon paint, and 5) copper oxide coating were applied to carefully prepared copper absorber plates. Olin Brass Roll Bond copper plates were tested individually in the same collector box configuration. This box was constructed with pressure treated lumber, insulated internally with two inches of polyurethane roof deck insulation (R = 14.29). Double strength window glass was selected for the glazing material.

The NBS Standard 74-635 was used as the standard test method for evaluating each collector configuration. Inlet water temperatures were varied to cover a wide range of operating temperatures in order to set limits on the affect of each coating on collector performance. Careful control of inlet temperature and coolant flow rate were maintained throughout the tests.

The paper will present results of the testing program used for this evaluation and will discuss the impact of these results on selective coating use. Statistical inferences will be developed to quantize the importance of the results. Illustrations of the test setup and graphical representations of the test data will also be included in the report.

ONE WAY VALVES: (FOR PV CELL COOLING, VACUUM, SEMI-V & HONEYCOMB COVERING OF SOLAR COLLECTORS; & ALSO AUTOMATIC FLUID/GAS/AIR FLOW CONTROLS)

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EXTENDED ABSTRACT

INTRODUCTION

This paper is first paper in a possible series of papers on energy applied physics of heat and pressure transfer technology. Potential applications range from simple gadgets, i.e. pens, vacuum cleaners, etc., to artificial petroleum and other chemical processes requiring high pressure and temperature. Detailed outlines of the two superbly practical devices for solar energy shall be given in the full-length. Ref. I is a list of related papers by the author.

BASICS OF THE TWO SOLAR ENERGY APPLICATIONS

Flat plate collectors can be concentrators. Concentrators with their expensive mirrors, lenses, sun-tracking by heliostats, etc. can be furnaces, if convective heat losses could be avoided as much as conductive and radiative losses are presently avoided. Hereby proposed is a device, possibly simpler than spark-plugs and easy to fit onto existing glass-covered solar collecting surfaces as easily as bottle cap fitting. The "anti-convective plug" may be a definite improvement on vacuum and semi-vacuum glass covers and honeycomb straw covers [Ref. II, 1, 2, 4]. Another proposal is a "coolant plug" to help photovoltaic cells in models whose efficiency is retarded by heat. [Ref. II, 3] The full-length paper shall try to answer general criticisms and scepticisms against solar energy which many still regard as a mere mirage. The given mechanisms shall be suitable for increasing mechanical efficiency. In this case efficiency of solar collecting surfaces by the formula:

$$\frac{\text{Product Outputs Values Gained}}{\text{Inputs (Captial \& Operating) Costs}} = 1 + \text{more} \left\{ \begin{array}{l} \text{in very low to very} \\ \text{high (wide range) of} \\ \text{temperatures} \end{array} \right.$$

Thr proposal is under consideration for possible patent protection, finance development and prototype manufacturing.

Conditions of Working

Even at sub-zero ambient temperatures, radiative energy sources (like sun in outer space) may suffice for the collector's superheating, provided convective, as well as, conductive heat losses are avoided. This methodology may have potential applications in low/variable temperature energy technology [Ref. I, 8]. The disadvantage of vacuum and semi-vacuum covers is that thick glass-covers may be needed and a small crack may ruin the entire

cover. Homeycomb paper-straw covers are liable to burn, and need constant directional adjustments for the best performance.

THE TWO IMPORTANT PRACTICAL EXAMPLES

Anti-Convective Plugs

Anti-convective plugs may be fitted on existing glass covers like bottle caps. It may adjust air inside to outdo both vacuum and semi-vacuum covers. Glass covering maybe thin, and small cracks maybe glued with simple everyday gums and so on. Functioning of the plug may also throw light on how honeycomb paper-straw covers work. It may also be applicable over glass coverings of concentrator surfaces and focuses. A simple adaption may also help insulation of deep freezes and solar storage. Usually only one such plug is required over each air/gas chamber cover.

Air Coolant Plugs

Practical examples are air coolant plugs which may be fitted to each glass cover over panels of photovoltaic cells which require cooling for maximum efficiency. Other uses include combining the anti-conductive plug to help heat a thermocouple in a thermovoltaic system. Coolant plugs may help keep the cole end cooler. Continued developments starting with an automatic temperature/pressure sensitive valves/flow regulators to help superheat carrier-fluid in phases (i.e. warming with waste-heat sideways, infrared, direct light, final superheating by ultraviolet selected rays) shall be proposed.

NATURAL (PHYSICAL, BOTANICAL, ZOOLOGICAL) & MECHANICAL EXAMPLES, LAWS OF GAS, HEAT & TEMPERATURE, ETC. UNDER WHICH THE DEVICE FUNCTIONS

These factors shall be discussed in the full-length paper. The proposed, generally uni-directional) flow regulation "Heat/Pressure Transfer Technology Applications" under which these systems are to function are well based on elementary laws like Charle's Law, Boyle's Law and so on, and does apparently have examples in natural and man-made (mechanical) phenomena as primary proof why the systems should work.

CONCLUSIONS

While the paper shall be devoted to the above said two simple and versatile applications, the final paper may also contain hints of possible future developments of "Heat/Pressure Transfer Technology" as provisionally listed below.

BIBLIOGRAPHY

References I (List of possible applications of uni-directional flow related technology)

1. and 2. are above given examples of anti-convective plugs and coolant plugs

3. Anti-Convection/Conduction Plugs for INSULATION of Deep Freeze, Solar and other heat-storages, etc.

4. Superheating in Automatic Valve Controlled Phases - viz. further Development of 1-way Valves as "Flat Plate Concentrators"

5. FLUID SELECTOR/FILTER VALVES/REGULATORS that may let through only sufficienctly heated molecules or requisite chemically changed fluid/gas - for use on collector-fluids, Bioconversion & Chemical Systems etc.

6. As a simple market gadgets applications - in ink-pens, vacuum cleaners, air-conditioned rooms,air filters, etc.

7. SIMPLE SOLAR DRIERS as a beginning in "Village Solar Technology" starting as an economically more attractive alternative to the present day uses of sun in drying etc.

8. LOW/VARIABLE TEMPERATURE TECHNOLOGIES APPLICATIONS. For further improvement of "Reverse of Fridge" heat concentrators for recovering factory waste/cooling heat. Like those developed in Hindustan Aeronautics Ltd., Bangalore, India and elsewhere.

9. HEAT IN/OUT change-switches for use in solar/heat storage salts and other temperature/chemical storage systems.

10. Applications in TEMPERATURE GRADIENT MOTION MACHINES. Including the one proposed for Cairo 1978 June Solar Energy Symposium which the author could not publish.

11. THERMOVOLTAICS

12. HIGH JET HYDRAL POWER SYSTEMS for fuller/cheaper utilization of enormous ptoential of high-altitude (even smaller volume) waters.

13. Certain very generalized Temperature/Pressure Applications.

14. DEEP PRESSES - a system for superhigh pressures cheaply delivered for artificial petroleum, liquid-hydrogen and such other chemical/physical processes requiring high temperatures and pressure

References II (to others published papers)

1. and 2. Regarding existing vacuum and semi-vacuum covers refer to any proceedings of major solar energy conferences; such as Serials 30 of the International Solar Energy Congress 1977, New Delhi, India (78).

3. See papers on photovoltaics in International Solar Energy Congress 1977.

4. Papers Nos. 1206, 0189, 0051 on "Honeycomb Paperstraw Covers", International Solar Energy Congress, 1977-78.

PERFORMANCE OF A FLAT TYPE SOLAR COLLECTOR COMPOSED OF THE SELECTIVE TRANSPARENT AND ABSORBING PLATES

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EXTENDED ABSTRACT

INTRODUCTION

The analytical and experimental results for the performance of a flat-plate type solar collector composed of a selective transparent plate and a selective absorbing plate are reported. The analysis of thermal property of the solar collector is spectrally made by means of considering heat balance caused by radiation, convection and conduction on both transparent and absorbing plates.
Glass, polyvinyl chloride, polycarbonate, acryl, and compound structure of two polymer plates binded with a honeycomb between them are adopted as specimens of the transparent plate. The transmittance of these materials was measured by an auto-recording spectrometer (0.36~25 microns) in our laboratory. Several kinds of selective surfaces made by plating, dipping, or chemical treating, for example, black nickel, black chrome, blue panel and copper oxide, and black paint for a nonselective surface are adopted as specimens of the absorbing plate.

RESULTS

Figure 1 shows that the experimental result on the performance of a glass-covered collector with a selective absorbing plate closely agrees with the analytical result calculated by the present method through each climate of four seasons. Therefore, the reliability of this analytical method was verified. The performance of various kinds of collectors of different combinations of transparent plate and absorbing plate was checked according to this analytical method as above in winter 1978 to 1979.
Figure 2 which was calculated for the nonselective absorbing plate, shows that the efficiency for a glass-covered or a compound polymer plate-covered collector was highest, and the efficiency for a P.V.C.-covered collector was lowest.
On the assumption of an idealized selective characteristic in

wavelength dependency, as shown in Figs.3 and 4, it is clarified that an influence of cut-off wavelength of absorbing plate to the collector efficiency is more effective than that of the transparent plate, optimum cut-off wavelength with the highest efficiency nearly exists on 4 microns, and the efficiency curve is widely flat around the optimum cut-off wavelength.

Figure 5 shows the relation between the incline of idealized selective characteristic and the collector efficiency around 4 microns. Therefore, the cut-off wavelength of the absorbing plate should mostly be shifted to longer wavelength than old ones except a few selective surfaces, and the wavelength dependency of the selective absorbing plate should be changed like a steep slope No.5 across 3.6 to 4.2 microns.

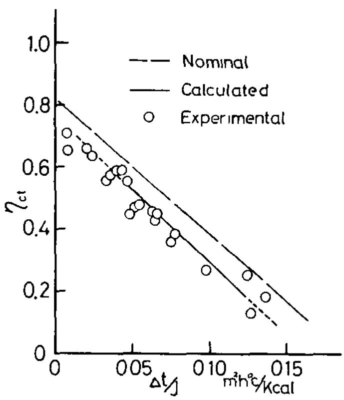

Fig.1 Comparison of the calculated and the measured for a collector performance.

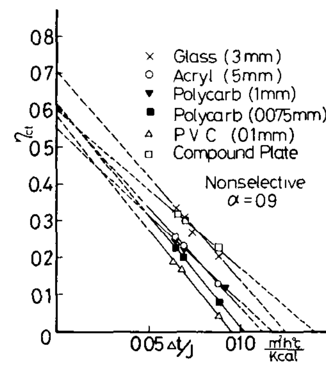

Fig.2 Comparison of the collector efficiency for several kinds of collectors.

NOMENCLATURE

η_{ct} : collector efficiency
J : solar radiation on the collector
Δt : difference between mean temperature at inlet and outlet of collector and ambient temperature
λ : wavelength of radiation
λ_c : cut-off wavelength
t_{wen} : inlet water temperature of collector
α : absorptance of selective absorbing plate
ε : emittance of selective absorbing plate
τ : transmittance of selective transparent plate

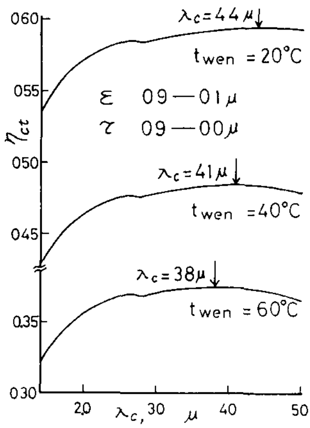

Fig.3 Optimum cut-off wavelength for the collector composed of the idealized selective transparent and absorbing plates.

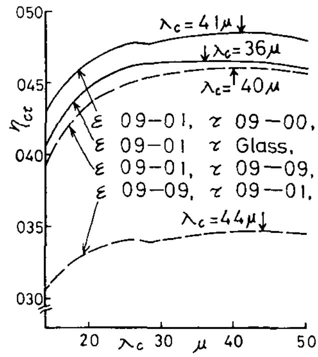

Fig.4 Optimum cut-off wavelength for the collectors made of a combination of the idealized selective and nonselective plates.

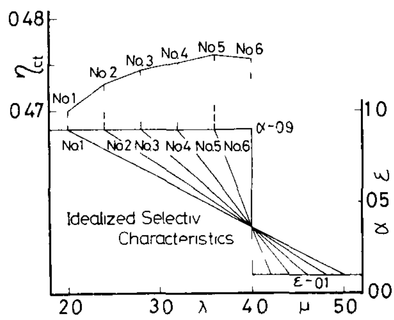

Fig.5 Influence of the incline of idealized selective characteristic to the collector efficiency,

KP

OPTICAL AND THERMAL ANALYSIS OF LINEAR SOLAR RECEIVER FOR PROCESS INDUSTRIES

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EXTENDED ABSTRACT

The requirement for high fluid temperatures to ahcieve reasonable thermodynamic conversion efficiencies has led to many complexities of the receiver design. The use of spectrally selective surfaces, honeycomb materials, vacuum enclosures and convection suppression cavities are often reported in the literature. A compromise between optics and engineering permits a cylindrical black body receiver with an opening parallel to the axis of the linear collector to be near economical. But at the line of maximum concentration of radiant energy in the receiver pipe, large temperature gradient exists. The considerable tempterature rise of the receiver wall above the working fluid temperature, causes greater thermal losses. To reduce this temperature gradient and hence lower thermal losses, Body et al [1] suggest a scattering surface in the receiver cavity (Fig. 1a) so that radiant energy would be absorbed after defocussing and scattering uniformly over a much larger internal area of the receiver cavity at the effective temperature of the paerture lower. This proposal involves high cost because of (a) increased fabrication cost of the receiver for the need of the true deflector surface so that view factor between deflector and rest absorber surface would approach unity and (b) skilled hand required.

Instead of putting deflector in the absorber cavity, it appears reasonable to design the receiver itself in such a way that the heat transfer rate is increased at the point of maximum concentration of energy. It can be achieved by an eccentric annulus receiver, Fig. 1b, providing maximum eccentricity that means more fluid bed at the point of maximum concentration in order to make effective absorber temperature lower. Based on thermo-optical considerations, the analysis and performance of such a system is investigated. This design has the advantage of its simple fabrication technology required with commonly available materials, which is best suitable in process industries.

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1. Boyd, D., et al, "A Cylindrical Black Body Solar Energy Receiver", Solar Energy, 18, 395-400 (1976).

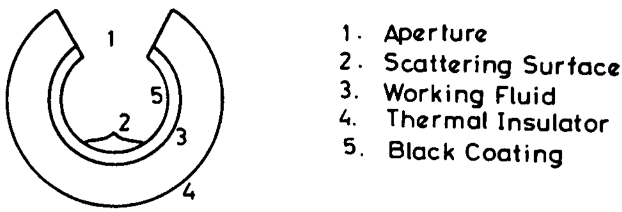

Fig. 1a - Boyd Receiver

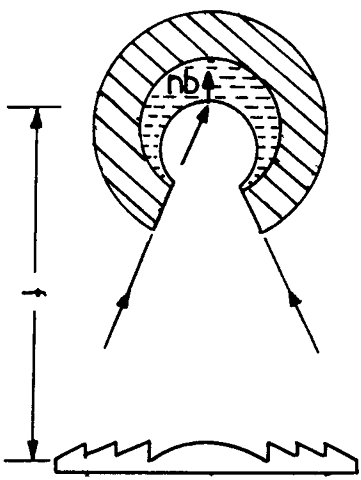

Fig. 1b - Proposed Receiver

ABSTRACT

The Construction and Use of Solar Indices in Architectural Design.

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This paper deals with two building design aids, it describes their rational, construction and method of use in the building design process when designing buildings for a hot-dry climate, where a minimization of the solar impact on external building surfaces is desirable.

The Insolation Index is a circular chart which makes it possible for the designer to carry out evaluations, on a comparative basis, of the various surfaces of the building in terms of their insolation during the overheated period of the year. The construction of this index involved the calculation of insolation numbers for surfaces of various geometries. By use of the Insolation Table form insolation numbers can be found, and thus evaluation of synthesised architectural forms is made possible.

The Orientation Index on the other hand, assumes more restrictions on the designer. It helps him to decide on the oriantation of his rectangular building and provides a numerical evaluation of the axial orientations which his design can adopt. This provides the designer with a clearer picture of the size of the energy implications of his decision.

The Plan Proportions Index, which is to be used with the Orientation Index, provides a systematic generation of the optimum proportions of a rectangular plan an architect can use inorder to provide an energy consious design of a building.

EFFECTS OF DUST ON THE PERFORMANCE OF THERMAL AND PHOTOVOLTAIC FLAT PLATE COLLECTORS IN SAUDI ARABIA-PRELIMINARY RESULTS

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EXTENDED ABSTRACT

INTRODUCTION

The effect of dust accumulation on the surfaces of flat plate thermal and photovoltaic collectors has been studied at the Research Institute/UPM, Dhahran and preliminary results are now available. The program was originated because there appear to be substantial differences in the literature on this topic; major solar projects requiring the information are underway in the Kingdom of Saudi Arabia; and dust storms are a characteristic climatological factor over much of the country. Recommendations in the literature on collector performance dust effects range from a correction factor of two percent [1,2] to a factor of thirty percent [3]. The two percent recommendation appears to be based on the work of Hottel and Woertz [4] in the Boston area of the United States while the thirty percent degradation in performance over a period of three days was described by Sayigh [3] from results obtained in Riyadh, Saudi Arabia. Garg [5] has measured the normal transmittance of direct radiation through glass and found that over a period of thirty days the transmittance decreased from ninety percent to thirty percent for a horizontal mounting. This data was obtained in Roorkee, India. The performance on actual collectors would probably not be affected to the same extent as the direct transmittance because the collector absorber plate would be expected to capture the forward scattered radiation which would not be available to the normal incidence pyrheliometer. The Sayigh and Garg results were obtained during the months of April, May, and June when dust storms are frequent and rainfall is minimal (or zero) in these areas. The results of reference [3] are somewhat difficult to interpret because the conclusions are based on an undefined temperature measurement in the collector while the degradation is described in terms of "heat collected". Results are also presented in [3] for effects of dust on a photovoltaic array. Here again, however, interpretation is difficult since the dirty and clean tests were done on different days and it does not appear that insolation measurements were made to reduce the data to a common base. We should note that information on changes in power generation for photovoltaic arrays is particularly important in view of the planned 350 KW solar village project to be located outside of Riyadh as part of the Saudi Arabian/U.S. Joint Solar Program [6].

It appears from the information in the literature that, as one would suspect, dust effects are site specific and that additional work in assessing these effects is called for.

Description of Experiment

Two thermal solar collector panels and one photovoltaic panel were tested during the course of the measurements. The first thermal panel was double glazed, had a non-selective surface steel absorber and was housed in an insulated fiberglass shell. The absorber plate was formed with integral headers and parallel risers. This unit had an aperature area of about 1.1 m^2. The second thermal panel was an evacuated tube, selective surface, reflector augmented unit with a gross area of approximately 2.98 m^2. Both panels were tested outdoors under natural sun conditions using the solar laboratory recirculating test loop with water as the heat transfer fluid. Efficiencies of the collectors under both clean and dirty conditions were determined by dividing the useful energy collected by the insolation measured in the plane of the collector. Temperature rise across the collectors was measured with either a calibrated differential thermopile or precision thermometers, flow rate was determined using a venturi flowmeter with a capacitance differential pressure transducer, and radiation was measured with an Eppley PSP pyranometer. The photovoltaic panel was a glass covered, sealed module of 36 silicon quarter circle segments with an active area of 11.0 cm^2. The PV panel tests were made at approximately solar noon. Current and voltage values were measured with calibrated instruments over the range from open circuit to short circuit conditions. From this data the peak power output, corrected for ambient temperature variations, was determined and the panel conversion efficiency was calculated by dividing this value by the total radiation on the plane of the module. Both thermal and photovoltaic panels were oriented due south for the tests and tilted at an angle of 26 degrees, the latitude of Dhahran.

Results and Conclusions

Data presently available suggest a decrease of peak power output of about 15 percent over a two month (May, June) period. Additional data for a longer time period will be available in the final conference paper. The efficiency change as a function of time is shown in Fig. 1.

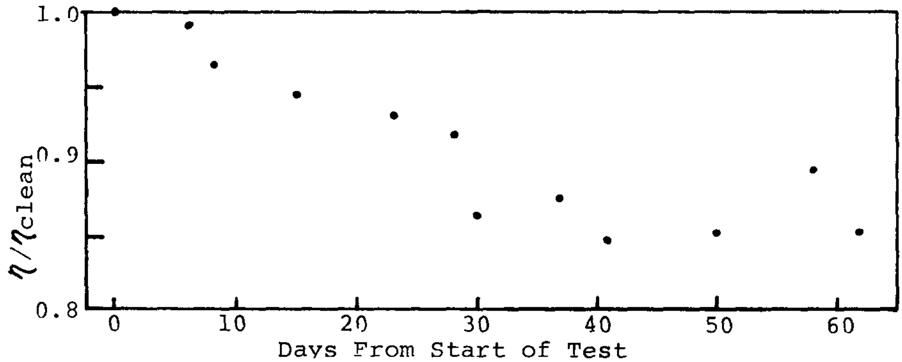

Fig.1 Degradation Due to Dust of Photovoltaic Panel Peak Power Efficiency, η

The F_R $(\tau\alpha)$ intercept for the double glazed thermal collector decreased by about 30 percent as a result of dust accumulated over a period of four months (March, April, May, June). These results are shown in Fig.

2. Results for the evacuated tube collector will not be available until the conference, but will be presented in the final conference paper.

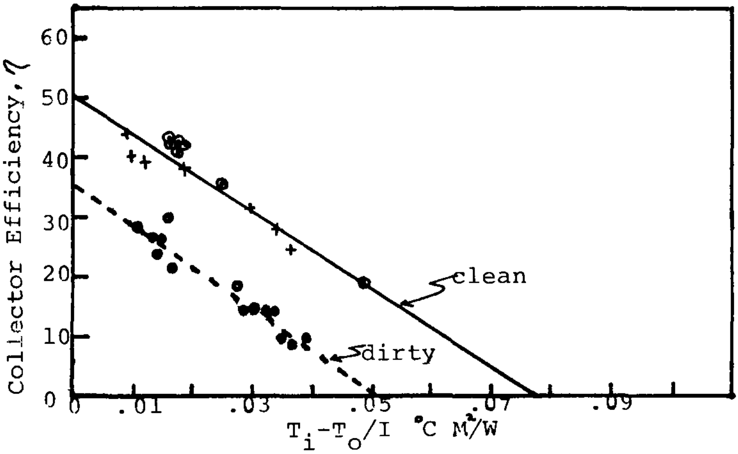

Fig.2 Dust Effect on Efficiency for Double Glazed Collector

The present findings lie somewhere between the small corrections usually found in the literature and those suggested more recently by Garg and Sayigh. Dust conditions in Dhahran are comparable to those in Riyadh but are aggravated by higher humidity levels which sometimes lead to a hardening of the dust layer on a cover. The months of testing for the results of reference [3] and the present work were the same and include the periods of highest sand storm activity. Continued work in this area will include airborne dust sampling, quantitative measures of dust accumulation and the effect on collector performance, and extension to focusing collectors.

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SESSION 3B

SOLAR HEATING AND COOLING I

Gup

A SIMPLE METHOD FOR COMPUTING THE DYNAMIC RESPONSE OF PASSIVE SOLAR BUILDINGS TO DESIGN WEATHER CONDITIONS

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Abstract

In contrast to the lengthy computations required to simulate hour-by-hour building performance using response-factor or thermal network models, design-day performance can be analyzed simply by using a method developed based on Fourier transforms. The paper describes how Fourier Building Response Functions are derived from building's thermal properties and show how the approximations made allow the results to be expressed as algebraic formulas which can be computed rapidly using a hand-calculator.

A program written for a hand-calculator which can perform this analysis requires as inputs, building design parameters such as "UA" products and specific heats of materials, and weather parameters. Since similar materials (e.g. frame walls and home ceiling) can be lumped together,data for only few different construction types are needed. Weather parameters are: daily solar gains for sunny and cloudy design days, length of cloudy design weather cycle, average ambient temperature of the design day, and typical diurnal temperature fluctuation. Output from program is hourly room temperatures for each of the design days.

PERFORMANCE CHARACTERISTICS OF A SOLAR HEATING SYSTEM ON THE LSU FIELD HOUSE

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EXTENDED ABSTRACT

INTRODUCTION

Most of the world's energy is derived from the sun, whether it be stored as fossil-fuel deposits (million of years), wind power (days, weeks, and months), water power or direct sunlight. The majority of the energy used on earth today is transferred from the sun. Nuclear power may be an exception.

There are already several thousands of solar hot water systems installed and operating throughout the world, particularly in moderate climates where freezing temperatures are not obtained. These rather simple devices have the inherent advantages that they operate effectively at low temperatures. The economic validity of somewhat more complex solar heating systems is subject to a number of variables which influence their competitiveness. These include energy costs in various regions, energy availability, building construction practices, and government tax incentives. Of concern to society as a whole is not only how competitive solar systems are at the present time, but how competitive they will be five to ten years hence.

Since both capital costs and fuel costs are rising, with fuel costs dominating, it appears that mass production of solar systems will become a major industry. However, a second facet of the solar utilization field concerns the engineering adaptation of solar systems to new and existing construction.

The main body of this paper includes performance data collected from a solar system installed on the Field House at Louisiana State University (LSU). The data presented was collected in December, 1978.

LSU FIELD HOUSE SOLAR PROJECT

A solar energy system was installed in August, 1978 on the field house at Louisiana State University and A&M College in Baton Rouge, La. The field house is used 14 hours a day, year round, by students and faculty for indoor athletics. It consists of a one-story center building, a two-story south wing and a two-story north wing. The feature space in the building is a large room of 66,500 square feet of floor area with a 51-foot ceiling. The building houses a running track and playing courts for basketball, volleyball, tennis and badminton. The total floor area is 101,000 square feet.

This paper is an evaluation of the solar heating system installed on the field house. The solar system is instrumented with forty-eight (48) sensors. From data collected, complete energy balances resulting in collector efficiency and portion of total energy supplied by solar energy will be presented.

The field house solar heating system is a retrofit project, designed to augment the original space heating and hot water heating systems. Water is used as the medium for transport of solar energy from roof-mounted collectors to a ground-level storage tank or directly to an interface with the building heating systems. Automatic controls for heating give priority to use of solar energy, thereby reducing energy consumption from auxiliary sources.

The solar system is expected to meet 28 percent of the total annual space heating and hot water heating load. This prediction is based on supplying domestic hot water at 140^{o}F, which is the design temperature for water leaving the hot water heaters. However, water used for the showers is constantly tempered to 115^{o}F at the shower heads. If water heated by the solar system is delivered to the domestic hot water system at 120^{o}F instead of 140^{o}F, and then tempered to 115^{o}F at the showers, the solar system can be expected to meet 34 percent of the total annual load.

Solar energy collection is performed by 309 Honeywell, Inc. flat-plate collectors, double-glazed with etched glass. Total gross collector surface area is 5,560 square feet with an effective collector plate area of 4,760 square feet. The collectors are mounted in five arrays on the roof of the south wing of the field house and face south at an angle of 45 degrees from the horizontal. Water is used to transfer energy from the collector arrays directly to a space heating air handling unit or the storage tank. Thermal storage is provided by 10,000 gallons of water in a steel storage tank with four inches of urethane insulation. The tank is located above ground. When solar energy is not available directly from the collectors, energy is supplied for heating from the storage tank. Domestic hot water is preheated by a heat exchanger in the storage tank. Auxiliary space heating is provided by hot water from two gas fired boilers. Auxiliary domestic hot water heating is provided by four conventional gas-fired water heaters. A purge unit in the collector loop will dissipate excess energy if collector water temperatures are excessive.

SOLAR REGRIGERATION: STUDY OF DRY ABSORPTION

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EXTENDED ABSTRACT

INTRODUCTION

The characters of the couple $CaCl_2$-NH_3 are examined in order to employ this binary compound for solar refrigeration ; the severe conditions imposed by the daily and nocturnal temperatures in tropical zones limit the choice of absorption systems. The solar refrigerator consists by a generator a condenser and an evaporator. It's an apparatus which works in two stages : vaporizing and condensing of ammonia during the day and regenerating during the night. No mobile device exists in this conception which represents an absorption refrigerator.

AIM

We must determine the necessary qualities of an adapted couple : this aim is easily attained with the study of diagram ($\frac{1}{T}$, Log P) for different concentrations of frigorigene liquid in the mixture salt-ammonia, the comparison of a few couples shows that $CaCl_2$-NH_3 is particularly well adapted to these conditions.
A relation exists between the pressure P, the concentration C and the temperature T.
Two problems must be resolved ; the first : to define the limit concentration in statics when T and P are given ; the second : to examine the quantity of ammonia liberated during the five hours of efficient insolation the rate of vaporization is also a function of the temperature attained by the flat plat collector and the pressure of ammonia vapour on the mixture. This pressure depends on the temperature in the evaporator. The essential period of time is that of the regeneration which produces the cooling. This depends equally on the temperature of the generator and on the concentration of the mixture. The rate of absorption depends closely on the area of contact : solid - vapour.

a) Physico-chemical aspect

The octoammoniacate $CaCl_2$, $8NH_3$ forms at the ambient. By heating we obtain a progressive dissociation following the schematic diagram which liberates 6 NH_3 per initial mole of $CaCl_2$ when the imposed conditions are those defined above.

$$CaCl_2 , 8\,NH_3 \xrightarrow[95^\circ]{} CaCl_2 , 4\,NH_3 \xrightarrow[106^\circ]{} CaCl_2 , 2\,NH_3$$

p(=16 atm) (condensor at 40°) + 4 NH_3 p(=16 atm) + 2 NH_3

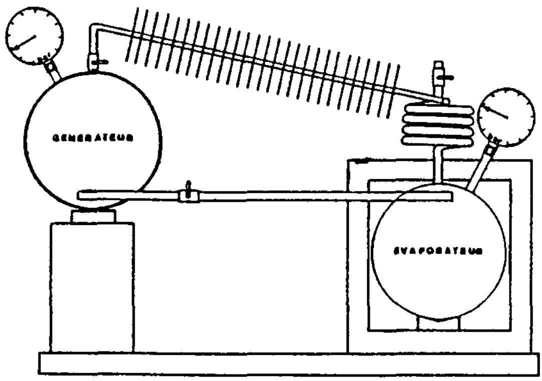
The separation of the remaining 2 NH_3 is only possible beyond 180°, therefore there can be no question of envisaging its use for refrigeration.
In total 102 g of ammonia are usable for 111 g of calcium chloride. If we refer to the comparison seen in wet absorption to 2 Kg 500 of $CaCl_2$, there is a corresponding 2 Kg 300 of ammonia, thus, taking account of the earlier dissociation these are 460 Kilocalories gross which characterise the cooling power of the salt, or 4 times more than with the binary water - NH_3.

b) Experimental thermostatic aspect

The diagrams (1/T, Log P) make it possible to compare the performances of the two mixtures NH_3, H_2O and NH_3, NaSCN. It was logical to draw experimentally the corresponding curves for the couple NH_3, $CaCl_2$.
With this aim in mind an apparatus was built in our laboratory allowing the study of these equilibriums between the ambient temperature and 140° C under pressure from 0,5 to 20 bars.
The diagram (1/T, Log P) for NH_3, $CaCl_2$ is analogous to those of other couples.
By the same calculations as the preceding ones it was found that for 2,500 Kg of anhydrous $CaCl_2$, 2,066 Kg of NH_3 disposable are obtained for refrigeration instead of the 2,300 Kg anticipated by stoechiometry.

c) Thermokinetics aspect

Operating by simulation on the preceding apparatus we are making a diurnal heating during 6 hours with constant energy. During 18 hours we observe the regeneration phasis. Thus we realise in the laboratory the real work ambience of the refrigerator. We ascertain a new decrease of the usable frigorigene liquids quantity : let it be so in mean 1 Kg of NH_3 for 2,500 Kg of anhydrous $CaCl_2$. In fact the active mass of NH_3 will be yet weaker.



appareil pour l'étude des équilibres NH_3CaCl_2

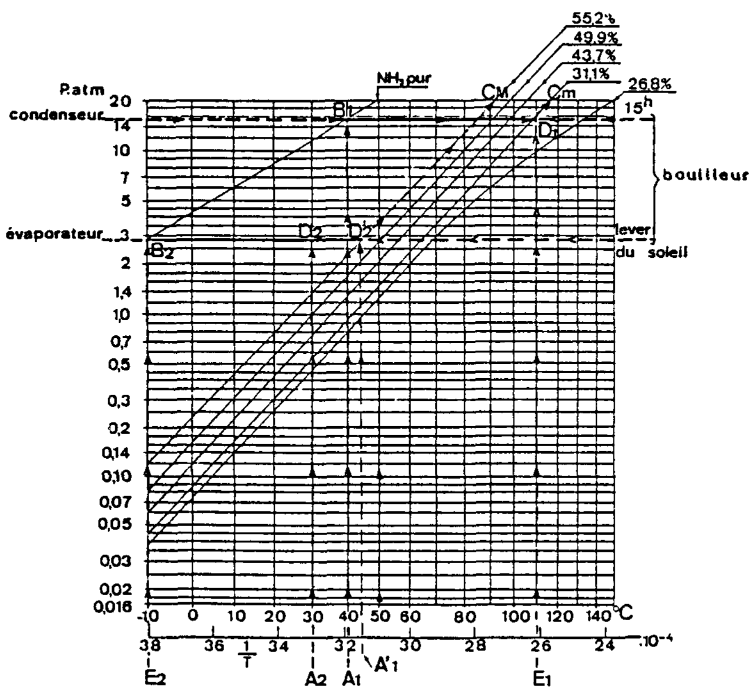


Diagramme $\frac{1}{T}$ log P pour le couple frigorigène NH_3 $CaCl_2$

JF

ALTERNATE ENERGY INSTALLATIONS ON THE JORDAN COLLEGE CAMPUS

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ABSTRACT

Since planning its first solar installation in 1974, Jordan College has conducted seven alternate energy demonstration units, some of which contribute greatly to reducing energy expenses. Comparative seasonal studies in progress are producing some informative and valuable data.

The two largest solar heating units range in collector size from 1,000 square feet to 2,080 square feet, while a retrofitted student residence has approximately 340 square feet of collector.

Costs for the installations range from $1,200 for a low technology retrofit application to $162,000 on a U.S. Department of Energy demonstration project using sophisticated technology and commercially available apparatus.

Solar heated air and water are utilized for space heating and domestic hot water, both separately and jointly. Collectors using Revere, Pittsburgh Plate Glass, Natural Resource Generation, and a unique do-it-yourself absorber configuration are used in the systems. The solar greenhouse, used by the Botany class, for experimentation uses passive solar with eutectic salt storages. The medium is Calcium Chloride Hexahydrate ($Ca\ Cl_2\ 6\ H_2O$) and is presently in development with Dow Chemical. A 4 KW Wind Energy Conversion System (WECS) provides light for the new solar greenhouse and the student lounge. The 110 D.C. machine is mounted on a 90 foot tower and energy is stored in a battery bank for use against non-wind days. A 50 Watt photovoltaic demonstration unit has been donated by Dow-Corning for teaching purposes. The Department of Energy recently announced funding on a $240,000 concentrating solar collector system for heating and cooling on the administration building in 1979-1980.

Through the use of planned and existing alternate energy installations, the Jordan College Energy Division will continue to offer its students and the people of Midwest America a solar demonstration and teaching facility second to none. Thus, by showing other institutions how the apparatus was secured, schools and industry are able to pursue possibilities in energy opportunities with information previously unavailable.

DIRECT SOLAR AIR HEATING IN DENMARK (56°N) HEATING STRATEGIES IN THEORY AND PRACTICE

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EXTENDED ABSTRACT

INTRODUCTION

The past five years have witnessed a dramatic increase in the study and the application of solar energy in Denmark. Many useful principles from the wealth of international literature have been applied to advantage. We estimate that more than $10^4 m^2$ collector were installed in this country by mid 1979. It now appears quite clear that the success of solar space and water heating here will be critically dependent upon the adoption of judicious heating strategies and construction practices.

Clearly the cash investment in solar equipment, expressed in terms of the total system cost per unit absorber area P_a is an important variable. This number and the total useful yearly yield Y_y per unit absorber area, when coupled with the expected system life-time and other economic variables, are of central importance. Because of the extreme yearly fluctuation in the available solar radiation and the heating load in northern climates, particular care must be exercised in order to achieve a successful matching of a solar heat source and a heating load. We have found the total yearly heating load per unit absorber area L_y to be a particularly important parameter.

In view of these observations, we have studied the performance of a variety of Danish solar heating systems. The following system types will be discussed: (A) a well-loaded hot water heating system, (B) a large-load direct air heating system with no active storage, and (C) a complementary water-air heating system. Practical experience with a variety of other system types has shown some systems to be inappropriate at present for use in northern climates. In our paper it will be possible to cite a number of practical solar design guidelines with a sound basis in both theory and observation.

HOT WATER HEATING

Hot water heating systems are becoming more and more common in Denmark. Figure 1 shows that yearly hot-water load per unit absorber area L_y equal to about 700 kWh/m^2-year or greater will assure that a well-designed water heating system can provide an annual yield Y_y greater than 300 kWh/m^2- year. Within a range of realistic economic parameters, such a system is already competitive with some traditional heat sources (central oil furnace, electrical resistance heating) though not with others (e.g. central heating plants). Actual prices and 5 year inflation rates will be reported in the paper.

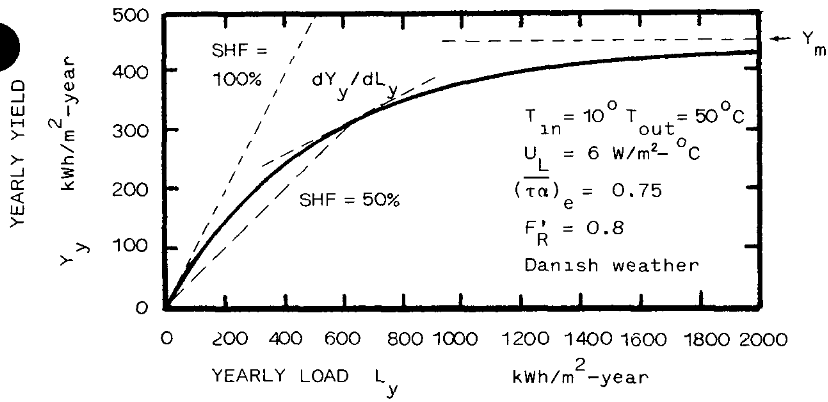

Figure 1: The useful yearly yield per unit collector absorber area is shown as a function of the total yearly load for a solar hot water heating system with constant load. The graph was generated using the f-chart method [1] for the parameters shown and Danish weather conditions. Klein's K_T method was used ($\rho = 0.2$) to determine monthly global on the 45° from horizontal south-facing collector.

Note that the slope of the chord line corresponds to the yearly solar heating fraction (SHF). This is illustrated for the case of SHF = 50%. Observe that the slope of the chord approaches unity for light loading conditions. Another asymptotic limit is the maximum annual yield Y_m approached for very high loading with consequent high system efficiency. The slope of the graph dY_y/dL_y corresponds to the marginal yield increase associated with a marginal increase in the system loading. Note that the graph can be approximately described by a function $Y_y = Y_m[1-\exp(-L_y/Y_m)]$, which is the solution to $dY_y/dL_y = 1 - Y_y/Y_m$. This simple relationship can be exploited in connection with an optimization analysis. The asymptotic performance limit Y_m can also serve as a figure of merit for a given solar heating system configuration.

As figure 1 clearly shows, the high useful annual yield necessary to achieve good economy depends critically on adequate loading. As a consequence, the solar heating fraction must decrease - a situation which will persist as long as efficient and inexpensive long-term storage is unavailable.

DIRECT AIR HEATING

Figure 2 illustrates the poor matching of the available global radiation on a south-facing surface (tilt 45°)

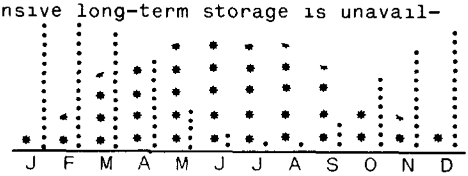

Figure 2: Insolation & Load.

in Denmark (each ✱ corresponding to 33 kWh/m^2-month) and our typical space heating load requirements (• = 300 kWh/month). Low outdoor ambient temperatures in winter aggravate the situtation. Autumn and particularly the spring are good periods for space heating with solar. Guided by the available literature [2] and by the importance of reducing system cost, we have proposed the use of direct air space heating with no active storage, delivering heat to a building when heat is needed and solar energy is available.

Such a heating system has been installed and operational in the natural sciences wing of Silkeborg Amtsgymnasium (community college) since late 78. The wing has a total yearly heating load of about 60 MWh/yr with only modest direct solar gain through windows. A south-facing (40^o) surface was available for a 33 m^2 single-pass air collector with two layers of 4 mm glass. A 1 kW blower distributes warm air to 4 lecture halls and a preparation area with a total floor space of 600 m^2, about 2/3 of the total wing area. Monthly performance summaries for the first 10 months of operation will be available in our final paper. The system has performed as projected with a yearly useful heat output of about 140 kWh/m^2 expected. Significant cost savings and simplicity were achieved by avoiding active storage. Blower energy requirements are lowered by avoiding storage and air-handling. High efficiency is maintained during operation, since the collector input temperature remains close to room temperature during all periods of operation.

COMPLEMENTARY WATER-AIR HEATING

A prototype collector designed to perform direct air heating when possible, and to store hot water otherwise, has been installed. A measurement program will reveal if the high loading inherent in this heating strategy can in fact produce high values of Y_y. In passing it is noted that an inexpensive microprocessor data-logging system designed for the AIM 65 microcomputer has been developed. Interested parties are welcome to address the authors for copies of our hardware schematics and software solutions.

CONCLUSION

The heating strategies suggested by earlier work [3] have been developed and tested. Our results will be presented more completely in our paper. Briefly, economically attractive solar heating systems for space and water heating in northern climates (above 50^o) should be designed to achieve: (1) high yearly system yield Y_y by high loading, (2) low cost by simple, maintenance-free construction, (3) good matching of the size, distribution, and temperature requirements of the heating load to the solar heating system.

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REPORT ABOUT THE MEASURING DATA EVALUATION OF THE FIRST LARGE-SCALE SOLAR HEATED BUILDING IN AUSTRIA

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The low temperature solar heating system of the Institute of Molecular Biology Salzburg of the Austrian Academy of Science is equipped with a microprocessor-controlled data acquisition and recording system, which collects the measuring data of 80 transducers like temperature sensors, heat flow meters, and meteorological probes.

After the description of the data acquisition and evaluation concept the most interesting results of the first 18 month observation period are presented. Detailed, computer-plotted energy flow diagrams show the heat losses of the different system components. It becomes apparent that the long term mean values of the solar collector efficiency are within the system significantly lower than it would be expected from the collector steady state efficiency specifications.

SESSION 3C

NUCLEAR ENERGY III

NUCLEAR FUEL SERVICE CENTERS

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EXTENDED ABSTRACT

The commercial nuclear power industry principally uses low enriched uranium (LEU) fuels in Light Water Reactors (LWR). However, the world-wide reserves of uranium are limited and, although the actual quantity remains to be established, it is generally agreed that these resources, which provide the only naturally occurring fissile isotope U-235, will be exhausted in the foreseeable future.

A means to extend the available uranium resources is to use breeder reactors, which operate on a uranium-plutonium cycle and convert the non-fissile but much more abundant isotope of uranium, U-238, to fissile plutonium. In order to make the plutonium available for use, it is necessary to establish reprocessing plants, to recover uranium and plutonium from the spent fuel, and fabrication plants, to manufacture the fuel. However, these operations introduce plutonium into the commercial sector in a readily useable form. This becomes a concern because of the increased access to and the potential proliferation of this weapons usable material (WUM). Consequently, analyses of nuclear fuel cycle alternatives, including new nuclear systems and modifications to existing systems are being undertaken, which would limit the availability of nuclear weapons using WUM from the commercial sector of the nuclear power industry.

This paper discusses International Fuel Service Centers (IFSC), in which the sensitive fuel cycle facilities are grouped into a common, heavily safeguarded site. The study described was initiated as part of the Non-Proliferation Alternative Systems Assessment Program (NASAP).

The IFSC concept is intended to reduce the risk of proliferation, while simultaneously using uranium resources more efficiently than the current LWRs without spent fuel recycle. The IFSC increases proliferation resistance by, 1) handling separated plutonium only within the confines of the IFSC, 2) designing the plant to combine reprocessing and refabrication of fuel at one site in order to minimize the capability for unauthorized diversion of WUM during transfer from reprocessing to fuel fabrication without detection, and 3) providing the necessary safeguards and proliferation resistance systems to prevent and/or detect unauthorized diversion of WUM from the IFSC.

The study described considered four types of centers to perform the following primary functions:

1) Spent Fuel Storage Center Only

   Receive spent fuel from dispersed off-site reactors for long-term storage.

2) Reprocessing Center Only

   Receive spent fuel from dispersed off-site reactors, reprocess the fuel, refabricate the recovered fuel for reuse in dispersed reactors, and process the high-level radioactive wastes for permanent storage elsewhere.

3) Pu Consumer/Energy Center

   Receive spent fuel from dispersed off-site reactors and on-site reactors, reprocess the fuel, refabricate the recovered fuel for reuse, in on-site converter reactors to extract the remaining energy value from the spent fuel fissile content, and in dispersed off-site burner reactors, and process the high-level radioactive waste for permanent storage elsewhere.

4) Fuel Producer/Energy Center

   Receive spent fuel from dispersed off-site burner reactors and on-site breeder reactors, reprocess the fuel, refabricate the recovered fuel for reuse, in on-site breeder reactors and in dispersed off-site burner reactors, and process the high-level radioactive waste for permanent storage elsewhere.

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THE LINEAR ACCELERATOR FUEL ENRICHER REGENERATOR (LAFER) AND FISSION PRODUCT TRANSMUTOR (APEX)

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EXTENDED ABSTRACT

Two major problems face the nuclear industry today; first is the long-term supply of fissile material and second is the disposal of long-lived fission product waste. The high energy proton linear accelerator can assist in the solution of each of these problems. High energy protons from the linear accelerator can interact with a molten lead target to produce spallation and evaporation neutrons. The neutrons can be absorbed in surrounding light water power reactor (LWR) fuel elements to produce fissile Pu-239 or U-233 fuel from fertile U-238 or Th-232 in-situ. A schematic of the target assembly for enriching PWR fuel elements is shown in Fig. 1. The enriched fuel element is used in the LWR power reactor until reactivity is lost after which the element is regenerated in the linear accelerator target blanket assembly and then the element is once again fissioned in the power LWR. In this manner, the natural uranium fuel resource can supply an expanded nuclear power reactor economy without the need for fuel reprocessing, which satifies the administration's policy of non-proliferation. Furthermore, the amount of spent fuel elements for long-term disposal is reduced in proportion to the number of fuel regeneration cycles. The limiting factor is the burn-up damage to the fuel cladding. A 300 ma-1.5 GeV (450MW) proton linear accelerator can produce approximately one ton of fissile (Pu-239) material annually which is enough to supply fuel to three 1000MW(e) LWR power reactors. With two cycles of enriching and regenerating, the nuclear fuel resource can be stretched by a factor of three without the need for reprocessing. The U-235 enrichment separative work requirements are reduced by a factor of four and the volume of spent fuel to be stored is reduced by a factor of two. Current estimates indicate that the LAFER fuel cycle would increase the cost of power by about 30% compared to present LWR power costs which is in the range of cost increases projected for the breeder reactor (LMFBR). As the natural uranium fuel resource becomes depleted, the LAFER becomes more competitive. Although viewed as a backup technology, the LAFER, on the one hand, is an alternative to the breeder reactor and on the other hand, it is also an alternative to isotope enrichment, i.e., U-235 separation either by gaseous diffusion, by gas centrifugation or by laser separation. The LAFER insures a long-term LWR power economy.

The fuel cycle can also be designed so that only stable fission products are removed from the fuel while the long-lived fission products remain contained in the fuel cycle. Thus, eliminating the need for long term waste management (APEX cycle). The transuranics and fission products are fissioned, decayed, and transmuted within the LAFER-APEX fuel cycle.

The use of the linear accelerator in the nuclear fuel cycle both as a fuel producer and as a fission product management tool, appears to be the missing link in the development of long term nuclear fission power. The technology of LINACs has advanced so that it is currently used as a highly reliable research tool. There is every reason to believe now that the LAFER can be designed and built as a high capacity reliable production tool. It is thus recommended that a strong effort be mounted for its early implementation.

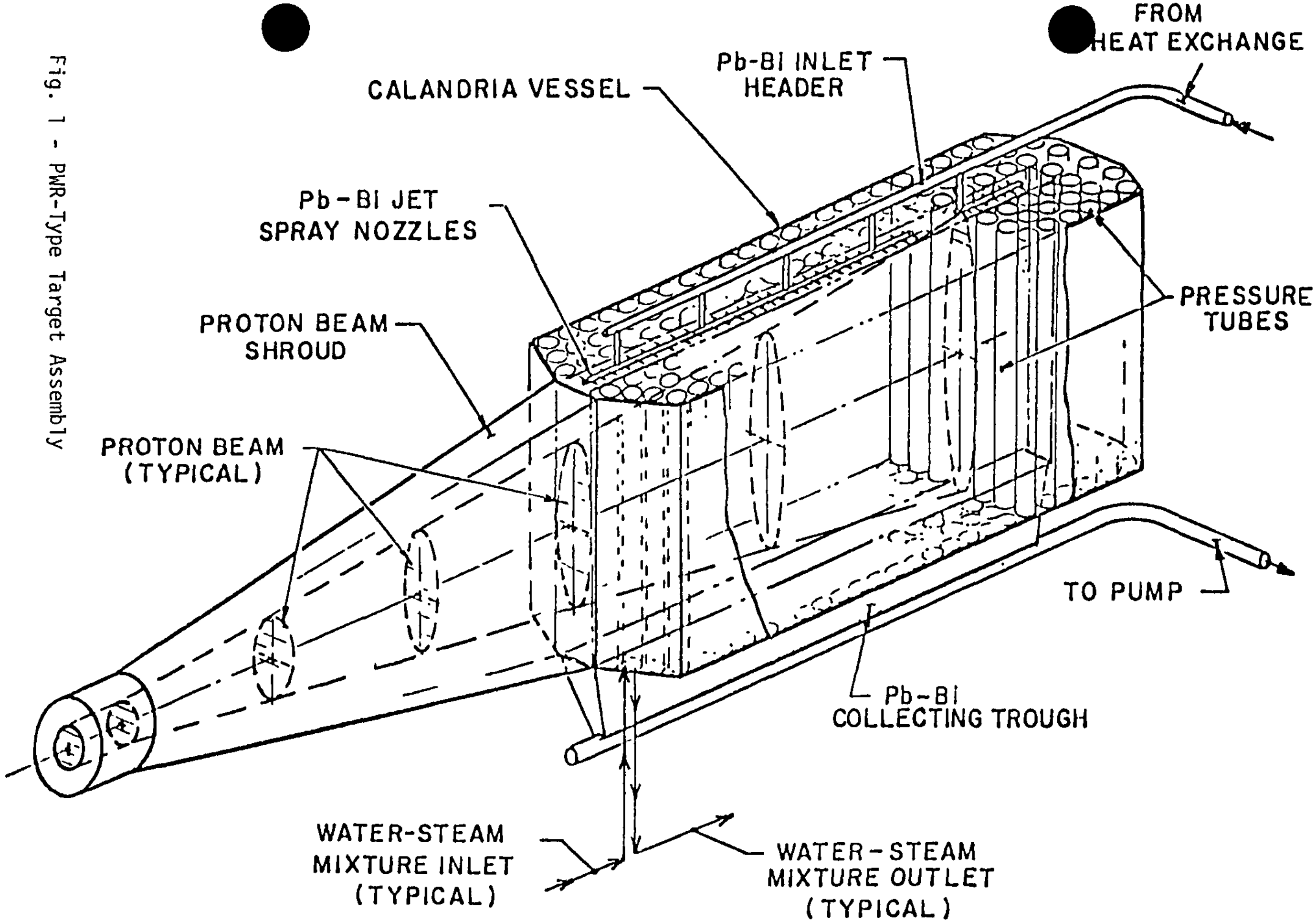

Fig. 1 - PWR-Type Target Assembly

Fig. 1 - PWR-Type Target Assembly

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NUCLEAR REACTORS CAPABLE OF IN-SITU FUEL REPROCESSING

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EXTENDED ABSTRACT

The apparent advantages fluid-fueled ractors offer over heterogeneous reactors include relatively simple and continuous fuel removal and in addition, the potential of continuous reprocessing, and a simple control system based on negative coefficient of reactivity. In light of recent developments of non-proliferation consideration, the second advantage which offers continuous in-situ reprocessing becomes important. The weakest link in regard to the proliferation risk from the nuclear fuel cycle is the spent fuel shipments from reactors. The easiest point of diversion, especially internationally, of SNM is probably during transportation. Diversion of fresh commercial LWR fuel would require the divertor to have enrichment capabilities before he/she can convert it to weapons materials. In the case of heterogeneous spent fuel, the plutonium contained in it can be separated out by simple chemical operations.

These transportation requirements for spent fuel and problems with long term storage capacity can be eliminated by the development of a homogeneous fluid fueled reactor which consumes nearly all the actinides fed into it, and has associated with it an on-line separation system to remove fission products. This type of design could avoid making it a likely point of diversion of nuclear materials.

A number of homogeneous reactor concepts have been proposed in the past, and carried to various stages of development [1]. This paper will focus on the Nitride-Liquid Tin Reactor concept.

Studies of nitrogen-nitride reactions in liquid uranium-tin alloys indicate the potential extension of this knowledge to a reactor fueled with uranium nitride. Uranium, dissolved in molten tin, is held in a graphite lined reactor vessel under a positive nitrogen pressure [2]. Solid UN is reversibly precipitated according to the reaction:

$$\underline{U} \text{ (dissolved} = \tfrac{1}{2} N_2 \rightleftharpoons \text{UN (solid)}$$

The fissioning of uranium alters the equilibrium between the nitride and the alloy. The nitride compound is destroyed and the fission products tend to dissolve in the tin alloy, while the freed nitrogen tends to react with the alloy to precipitate more fuel nitride. The fission products form low density nitrides and float as a slag. By removing this slag the waste can be continuously collected while the reactor is operating.

The self-control feature for the reactor arises from the UN equilibrium with the alloy and the effect of temperature in this equilibrium. If the heat demand increases, the drop in core temperature would cause more UN to precipitate from the alloy, increasing the critical mass leading to recovery of temperature. Similarly, should the core of the reactor rise excessively in temperature, the UN readily decomposes and the uranium redissolves in the alloy, decreasing the critical mass. The result is that the core temperature and fuel equilibrium are inherently stable depending only in the nitrogen pressure and alloy concentration.

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CURRENT DEVELOPMENTS IN NUCLEAR BREEDER TECHNOLOGY

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EXTENDED ABSTRACT

Nuclear energy is currently providing, on a national average, about 13% of our electricity requirements with the proportion being much larger in the northeast and the midwest. The Department of Energy's latest estimates for the electric generating capacity provided by nuclear plants at the end of the century are in the range of 235-300 gigawatts. Essentially all of this capacity will be provided by light water reactors (LWRs) which derive their energy from the "burning" of the uranium isotope U^{235}. Even with these lowered forecasts the timely introduction of Liquid Metal Fast Breeder Reactors (LMFBR) is essential in assuring a continued supply of fuel for an integrated nuclear generating system in the post 2000 era [see Reference (1) for more details].

Development of LMFBRs dates back to the Manhattan Engineering District days in the early 1940's. The first experimental fast reactor, Clementine, went critical in March 1946. Clementine was followed, domestically, by EBR-I, LAMPRE, EBR-II, Fermi, and SEFOR, all of which achieved criticality, FFTF, with criticality in late 1979, and CRBRP which is currently in the design and fabrication phase. This progression of reactors was part of a continuing development and test program leading to semi-commercial plants in the 1990s and true commercial deployment early in the next century. France, Germany, the UK, Japan, and Russia have had similar programs with similar objectives. (See Reference [2] for more program details).

In April 1977, President Carter announced a dramatic change in the policy of the U.S. Government toward the development and commercialization of the LMFBR. The new policy shifted the emphasis of the U.S. program away from the planned program of constructing and operating progressively larger test, demonstration, and commercial prototype reactors, and turned instead toward more broadly-based breeder research and development activities, similar to those conducted in the U.S. in the 1950's and 60's and called for an international study of alternate nuclear fuel cycles. As part of the new U.S. policy, the ongoing Clinch River Breeder Reactor Program (CRBRP) was to be terminated and the scheduled 1986 date for deciding if the LMFBR was to proceed toward commercial status in the U.S. was abandoned. In the period since April 1977, the CRBRP has been continued at the insistence of Congress while foreign countries have re-emphasized their commitment to the development of the LMFBR.

Despite the change of emphasis in the LMFBR program, President Carter has stated that the nuclear option must be retained. In order to retain nuclear generated power as a viable option, LMFBRs must be developed and deployed. An industry view of the time required for such deployment is presented in Reference [1]. Under the Administration program a Conceptual Design Study (CDS) was established in October 1978 to "...develop a viable breeder option for the future." The project will carry out an evaluation and design of a large LMFBR rated at 650 to 900 MWe.

The design study is being conducted in two phases. The first phase, running until March 30, 1980, consists of independent evaluations leading to recommendations on the important design parameters and other characteristics of the proposed plant. This phase includes engineering analyses, trade studies and evaluations of principal plant and fuel systems design variables and alternatives, and selection of those designs which represent the most effective plant conceptual design basis for the succeeding work.

Following DOE evaluation of the Phase I work, Phase II will focus on the conceptual design of a single plant. The conceptual design is scheduled to be completed by March 1, 1981. It is intended that Congress and the President will then make a decision whether or not to proceed toward construction.

During the past several years the Advanced Reactors Division (ARD) of Westinghouse has been investigating conceptual designs of a 900 MWe LMFBR. Designs have been evolved for both a "pool" configuration and a "loop" configuration. Although "pool" and "loop" are generally accepted designations, more descriptive terms might be "integrated" and "dispersed" designs. In the pool concept, heat is transferred from the core to primary sodium contained in a reactor vessel and then transferred to a non-radioactive secondary sodium system via intermediate heat exchangers (IHX) contained within the reactor vessel. The secondary sodium is pumped to steam generators outside the containment building. In the loop concept, heat is transferred from the core to primary sodium which is pumped from the reactor vessel to IHXs located in inert gas filled cells surrounding the reactor vessel where the energy is transferred to a secondary sodium system. From this point, the loop configuration functions in a manner similar to a pool system.

The Westinghouse Large Loop Reactor (LLR) is a four loop type LMFBR. The reactor vessel is spherical with a cylindrical upper portion and a flat closure head on top. It is supported at its midplane from the reactor cavity. Three rotatable plugs are supported from the vessel top flange. The vessel is suspended within a guard tank which is supported from the wall of the reactor cavity. External insulation is used on the guard tank and nitrogen is used to cool the reactor cavity between the guard tank insulation and the concrete walls. The cavity cooling gas also cools the top of the reactor vessel and aids in establishing an acceptable thermal gradient in the vessel upper wall and flange.

The core support structure (CSS) and support cone are welded to the ring forging of the vessel. The CSS supports the weight of the nuclear core, the in-vessel shielding, the in-vessel fuel transfer station, and the thermal liner components. This conical support serves as a pressure boundary between the cold inlet sodium and the intermediate bypass sodium.

The Westinghouse Large Pool Reactor (LPR) is a hot pool type LMFBR. The cylindrical reactor vessel (70 ft. in diameter) has a hemispherical bottom head, and is supported from a cold structural deck. Six IHXs, four modular primary pumps, three rotatable plugs, and other auxiliary reactor equipment are supported from the deck. The deck is supported from its periphery and uses radial keys to transmit lateral seismic forces to the reactor building. The vessel is suspended within a guard tank which is independently supported from the wall of the reactor cavity. External insulation is used on the guard tank and nitrogen is used to cool the reactor cavity between the guard tank insulation and the concrete walls. The cavity cooling gas also cools the top of the reactor vessel and aids in establishing an acceptable thermal gradient in the vessel upper wall to minimize stresses where the hot vessel is joined to the cold deck.

A conical lower support structure (LSS) and a vessel sodium shield are welded to the wall of the vessel. The LSS supports the weight of the nuclear core, the in-vessel shielding, the in-vessel fuel transfer station, and the plenum separator system components. This conical support structure serves as a pressure boundary between the cold sodium pool and the intermediate and hot sodium pools.

A principal component of the reactor vessel system is the sodium shield; a cylindrical shell which extends from just above the region where the LSS is attached to the reactor vessel to within four inches of the bottom of the deck. This shield prevents sodium from contacting the vessel wall above the LSS, and thus, establishes a cover gas annulus between itself and the vessel. Reflective plate insulation is used within the upper part of the annulus, adjacent to the deck structure, to passively control the axial thermal gradient in the vessel shell. The reactor design uses an intermediate volume of sodium to thermally separate the hot and cold plena. This intermediate sodium plenum is contained by plenum separators, which promote thermal stratification of the sodium between the hot and cold pools.

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STUDIES RELATED TO PROTECTED LOSS OF FLOW ACCIDENTS IN A FAST BREEDER REACTOR*

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EXTENDED ABSTRACT

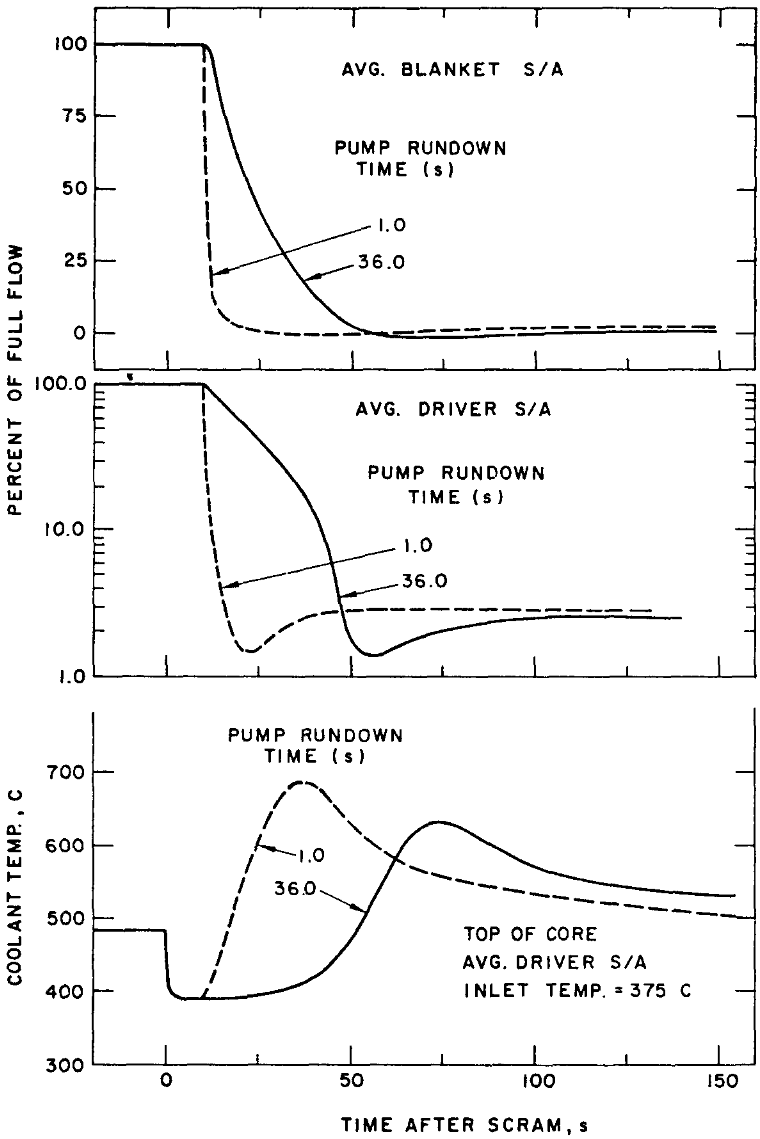
During the normal operation of a liquid-metal-cooled fast breeder reactor (LMFBR), fuel temperatures are controlled within prescribed limits by the forced circulation of liquid sodium. However, during certain events postulated to occur during the operating life-time of a reactor plant, power to the primary pumps (which maintain the forced flow) can be lost. As the forced flow starts to decrease, the plant protective system will, with extremely high reliability, shut down the plant. However, due to the generation of radioactive material within the fuel and structural components of the reactor during power operation, a certain amount of residual decay heat will be released, even though the primary fission reactions have ceased. Therefore, there must be some continued circulation of coolant, albeit at a much reduced rate, following this event in order to prevent an undesirable overheating of the reactor.

Prudent engineering design necessitates the inclusion of at least one back-up system to provide sufficient coolant flow to maintain reactor temperatures within prescribed limits. Particular systems which have been designed include redundant electrical power supplies, "pony-motors" on the primary pumps which may be powered by diesel generators, auxiliary pumps driven by storage batteries, completely separate and redundant decay heat removal systems, or other related concepts, all of which provide some form of emergency electrical or mechanical energy supplies. However, in order to assure continued reactor coolability even in the extremely remote event of a complete failure of these types of engineered systems, the main and auxiliary heat transport circuits of the plant are designed in order to promote natural circulation of the coolant driven by buoyancy. Thus, the natural circulation capability of a plant is the ultimate, "fall-back" heat transport mechanism of reactor cooling.

This paper will present the results of an extensive analytical and experimental program designed to study the dynamics of natural circulation in an LMFBR. A wide range of protected accidents are considered, all of which involve losses of forced coolant flow. The effects of reactor operating

history, balance-of-plant conditions, sequence of reactor scram and pump trips, etc., upon peak reactor temperatures are presented. As a result of these studies, a number of plant design options are described and discussed.

One of the more important design options in terms of its impact upon the transition into natural convective decay heat removal is the rundown time of the primary pumps. Generally speaking, the longer it takes for the pumps to run down, the lower the peak transient core temperatures will be. However, there are exceptions, essentially due to the two counteracting phenomena occurring during pump run down: first, the longer it takes the pumps to reach zero speed, the lower the reactor decay heat will be when the transition to natural circulation must occur, but second, the longer the period of overcooling which occurs during the time the pumps are running, the lower the net system buoyancy becomes, causing an adverse condition for a transition to natural circulation. These effects are of comparable importance for pump rundown times in the range of about 0-30 seconds, but for longer periods, the reduced decay heat level becomes dominant. Typical resulting top-of-core coolant temperatures for several pump transients following a complete loss of all on-site electrical power are shown in the attached figure.


AVG. BLANKET S/A
PUMP RUNDOWN TIME (s)
1.0
36.0
AVG. DRIVER S/A
PUMP RUNDOWN TIME (s)
1.0
36.0
PERCENT OF FULL FLOW
100
75
50
25
0
100.0
10.0
1.0
PUMP RUNDOWN TIME (s)
1.0
36.0
TOP OF CORE
AVG. DRIVER S/A
INLET TEMP. = 375 C
COOLANT TEMP., C
700
600
500
400
300
0
50
100
150
TIME AFTER SCRAM, s

RMS

EXPLODING THE MYTHS ABOUT THE FAST BREEDER REACTOR

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EXTENDED ABSTRACT

INTRODUCTION

In the face of a gloomy energy picture, and contrary to the progress made by other nations, the Administration has chosen to slow down the U. S. fast breeder program and terminate the Clinch River demonstration plant.

What drove the President to make this serious error has been a very effective campaign of myths and half-truths by a small group dedicated to discredit nuclear power technology and to exaggerate the breeder's hazards.

Following are the major issues raised and the true facts that relate to each:

Myth No. 1: Conservation will defer the need for the breeder until after the turn of the century.

While conservation should be supported vigorously, predicted national energy demand reductions are optimistic. Electricity will be needed increasingly to replace oil and gas use, and the disadvantages of an expanded coal industry will perpetuate the energy crisis.

Myth No. 2: The Clinch River Project is too costly and obsolete; we can buy breeder technology from abroad.

Compared to other energy source costs, the Clinch River Project represents a bargain, and its design is based on an orderly evolution. Buying technology from abroad will result in practical difficulties and will make us dependent on foreign control.

<u>Myth No. 3</u>: Nuclear bomb design and manufacture from reactor-grade plutonium is not difficult.

Power reactor plutonium is significantly different from military grade plutonium, and the construction of a workable nuclear weapon is more technically difficult than designing such a device from available literature.

<u>Myth No. 4</u>: Plutonium can be diverted from nuclear power plants.

Plutonium is presently protected by an elaborate safeguard system. Moreover, the recently announced Civex process would avoid purifying plutonium into weapons grade material at any stage in the fuel cycle.

<u>Myth No. 5</u>: There is no solution for the disposal of radioactive wastes.

Wastes from the weapons program have been safely handled for 30 years, and presently, over 90% of the wastes are from the military. Technologies exist for treating and fixing high level wastes.

<u>Myth No. 6</u>: Plutonium is the most toxic substance known to man.

There are a variety of more easily available substances that are more toxic than plutonium. Investigation of the "hot particle" theory has shown it to be invalid.

CONCLUSIONS

The U. S. is not proceeding with a high confidence strategy for breeder development because of a variety of false assumptions. Completion of the Clinch River Project will provide us with a breeder option insurance policy and will offer the U. S. an opportunity to implement non-proliferation objectives.

ENERGY FOR THE FUTURE - THE BREEDER REACTOR

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EXTENDED ABSTRACT

the world supply of fossil fuels dwindle and the price per btu goes out of site", America and other countries must transition to long-lasting sources of energy.

Energy experts project that perhaps 20% of electrical energy in the United States in 2000 A.D. will be derived from a combination of solar, hydro, oil, gas, geothermal, wind, ocean tides, temperature gradients and thermonuclear fusion. The big question -- from where will the other 80% of needed btu's be delivered. Coal and uranium will, without doubt, make major contributions. However, if nuclear in the U.S.A. is to play an increasing role and remain competitive, artificial fuel will be needed to complement natural supplies of Uranium-235. Breeder-type power plants can help meet electrical energy demands and convert fertile material to artificial fuel.

Energy managers must administer differently in the future than in the past in order to have adequate transportation fuels as well as fossil furnace fuel for electrical power plants. Today jet planes sit in hangers because of fuel shortages. Jet planes cannot burn coal, split atoms or operate by hydro. Power plants, if designed and built to do so, can burn coal, split atoms and operate by hydro power. Why "rob Peter to pay Paul"? Nuclear power via breeders will give energy managers a tool to expand decades of nuclear fuel to centuries.

While the U.S. Department of Energy pushes forward with a broad base Liquid Metal Fast Breeder Reactor Research and Development Program, the electrical power industry is making an effort to demonstrate the feasibility of a breeder power plant within a utility setting. In fact fabrication is more than 60% complete on several components and sub systems for the Clinch River Breeder Reactor Plant at Oak Ridge, Tennessee.

e CRBRP has been the source of much academic discussion in recent years. The end results of this project may well determine the ability, determination and credibility of the United States to plan a major electrical project of an innovative nature and follow through.

More than 750 electrical organizations have provided financing for both fabrication and information in-put related to breeder power plant design and manufacturing in the United States. The Breeder Reactor Corporation which administers projects with financing from the utility community disseminates information via its own Information Staff and by

contract to an education and research organization. The presentation today was made possible by contractual arrangement between the Breeder Reactor Corporation and Oak Ridge Associated Universities - Energy Education Division. This program is available free to civic clubs and service organizations on a nation-wide basis. Also, literature which answers ten of the most common questions on LMFBR's is available to each civic and service organization attendee.

SESSION 3D

GEOTHERMAL ENERGY II

MAKING GEOTHERMAL POWER COMPETITIVE

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EXTENDED ABSTRACT

Combinations of technology improvements have the potential to substantially reduce the cost and increase the supply of competitive geothermal energy. Under current conditions, new base-loaded nuclear and coal power plants would generate electricity at 25-35 mills/kWh at the busbar. Similarly, new oil-fired plants would generate electricity at 50-60 mills/kWh at the busbar. Using these costs for reference, by 1985 about 80% of the identified hydrothermal resources would become competitive with oil and about 60% would become competitive with coal and nuclear. This presumes, of course, that the energy costs from conventional power plants remain constant in today's terms while the costs of geothermal energy decrease in response to technology improvements and economies of scale and mass production.

This paper presents the near-term supply curve (Figure 1) for electric applications of geothermal energy and illustrates the potential impacts of some improvements in technology. The near-term supply curve is based on energy production costs calculated using the GEOCOST[1] model and is intended to represent current state-of-the-art technology. We used the subsurface temperature, reservoir thickness, and heat content estimates made by the USGS[2] for the identified high-temperature and intermediate-temperature hydrothermal resources of the Western U.S. to derive this curve.

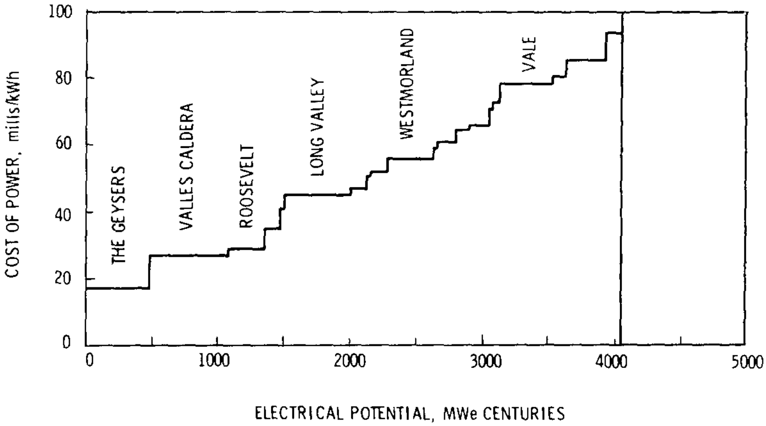

FIGURE 1. Near-Term Supply Curve for Electric Applications of Geothermal Energy

Each step in the curve is composed of one or more geothermal resources identified by the USGS, as indicated for several of the steps on Figure 1. Both high-temperature and intermediate-temperature resources were included up to an arbitrary cost ceiling of 100 mills/kWh. For the near-term we excluded the high-temperature hydrothermal resources in Alaska, the Salton Sea, and the National Parks. The step function appearance of Figure 1 is caused by the existence of "blocks" of geothermal resources with identical subsurface temperatures and reservoir depths. For example, the 500-MWe-centuries block in the lower-left corner represents the dry steam resource at The Geysers, which yields the lowest cost of power of all the hydrothermal resources. Resource quality decreases as you move up and to the right on these curves, and thus, the cost of power increases[3].

Supply curves are tools used in economic analysis. They are graphical representations of relationships between costs and quantities of goods, from the producer's point of view. Specifically, the supply curves that we have derived relate geothermal electrical potential to production costs for the hydrothermal resources identified by the USGS. To the extent that a particular technology improvement can lower the production cost at certain sites, it can cause the supply curve to shift downward. To the extent that it can increase the supply of energy available below a certain cost ceiling, it can cause the supply curve to shift to the right.

Figure 2 shows the smooth curve which we have drawn to represent the step function shown in Figure 1, since it is easier to visualize shifts in cost or quantity if the supply curves are smooth rather than step functions. The long-term supply curves illustrate the potential shifts in the near-term supply curve which would result from certain technology improvements currently being researched under DOE funding. Curves were drawn to show the impacts of combinations of technological advances expected to be achieved by 1982 and 1985 (Figure 2). We show that through a combination of significant techno-

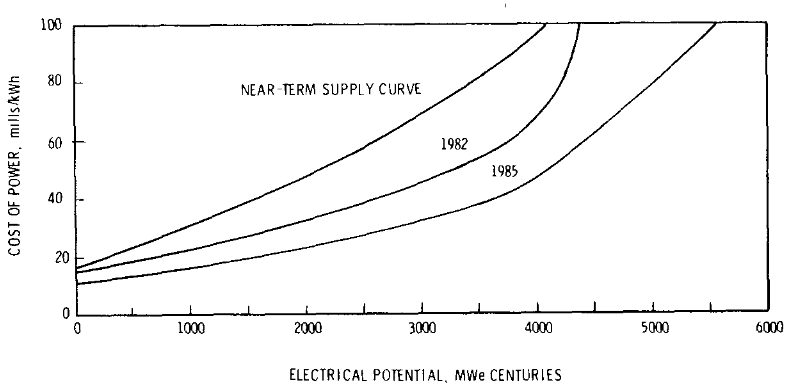

FIGURE 2. Long-Term Supply Curves for Combinations of Technological Advances

logical advances, most of the identified hydrothermal resources could become competitive with conventional energy sources for electric power production by 1985. More specifically, about 4,450 MWe centuries (equivalent to 14,830 MWe for 30 years) may be competitive with oil by 1985; about 2,800 MWe centuries (or 9,330 MWe for 30 years) may be competitive with nuclear and coal[4].

ACKNOWLEDGEMENT

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LOW-GRADE GEOTHERMAL ENERGY: FEASIBILITY AND DEMONSTRATION AT REGINA, CANADA

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EXTENDED ABSTRACT

Porous and permeable sandstones and carbonate rocks deeply buried in sedimentary basins contain large volumes of water at temperatures of 50° C to 150°C. The hot water in these deep aquifers is produced and used extensively for space heating in France, Hungary and USSR. There is heightened interest in this source of low-grade heat energy in Denmark, Sweden, Germany, eastern United States, and elsewhere. The Geothermal Feasibility Project at Regina is designed to test and demonstrate usage of the widespread and large Canadian resource. The main sponsoring agent to date (late 1979) has been the Earth Physics Branch of Energy, Mines and Resources Canada.

A geological feasibility study of the Regina-Moose Jaw area, completed in 1978, was based mainly on exploratory wells drilled for petroleum with some seismic work. The area is situated on the northern flank of the Williston basin, a geological structural depression that centres in western North Dakota. The sedimentary fill above the Precambrian Basement is about 220 m (7,200 ft.) thick. The fill consists of a basal unit of sandstone and shale about 200 m thick (Cambrian and Ordovician), a medial unit of dolomite, limestone, anhydrite and bedded salt about 1,000 m thick (Ordovician to Mississippian) and an upper unit of shale and sandstone about 1,000 m thick (Jurassic and Cretaceous). From the geological study we concluded that sandstones in the basal unit were the most favourable geothermal target in terms of water productivity, temperature and water chemistry.

Following the geological feasibility study, an exploration-production well was drilled on the University of Regina campus to a depth of 2,215 m (7,267 ft.). The test has confirmed the presence of porous and permeable sandstones at depth 2045-2209 m (6709-7247 ft.) containing saline water at elevated temperatures. The well has been completed with 178 mm (7in.) casing set at 2044 m and 222 mm (8 3/4 in.) open hole at 2044-2215 m. Bottom hole temperature is 62°C to 63°C. Reservoir properties are favourable with pumping tests indicating that at a flow rate of 100 m^3/hr (440 US GPM) the stabilized drawdown below surface will be 90 to 100 m. The estimated power required for pumping the source well is 45 to 50 kW. The water contains 10% solids, mostly sodium chloride. Dissolved H_2S in some zones may be troublesome but dissolved oxygen and silicon are low. Because the water is very saline, a disposal well will be constructed at a distance of 1 km to 2 km and the cooled water will be reinjected into

the same reservoir unit.

Initially the low-grade energy will be extracted from the water at the surface using a heat exchanger and will be used to heat campus buildings. The wells will be utilized on an intermittent (seasonal) basis. Study of the transient heat transfer characteristics of the producing well show that the brine temperature at the wellhead will approach a steady state value within three weeks after a normal flow rate (100 m^3/h) is established. A steady state analysis correlated brine flow rate and heat losses from bottom hole to surface and obtained brine temperature as a function of depth. This analysis showed that the brine temperature at the well head will be about 3°C lower than the aquifer temperature so that, when steady state conditions are approached, the water will reach the surface at an estimated 58°C. Assuming that this water can be cooled to 33°C in the heat exchange system, the gross thermal power available at a flow rate of 100 m^3/h is 2.9 mW.

We have investigated in preliminary manner the utilization of the low-grade geothermal energy to heat an enclosed sports complex (field house) of approximate area 9,200 m^2 (100,000 $ft.^2$). The worst case heating requirement for this building is 1.9 mW (6.5 million Btu/hr.). The defined system uses baseboard heaters at the building perimeter and conventional water/air heat exchangers to heat the building intake air. Early analysis shows that heating equipment costs with this system would be comparable to a conventional heating system using fossil fuel. A significant amount of available heat energy (at temperatures above outside air temperature) would be rejected, however, or would have to be used in some other manner.

In order to improve utilization of the available low-grade geothermal energy we are investigating usage of heat pumps and greenhouse complexes and we are examining building design concepts which utilize floors, ceilings and walls as heat transfer elements as well as structural elements of a building.

THE UTILIZATION OF GEOTHERMAL ENERGY IN THE PHILIPPINES

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EXTENDED ABSTRACT

Just like other countries in the world today, the Philippines is trying to look for alternatives to the conventional source of energy of which the supply is not unlimited. Research and development projects are undertaken in the fields of solar, wind, and wave energy, biogas, natural gas, coal mining, nuclear and geothermal energy. Of the non-conventional sources, geothermal power generation got an unusually high financial allocation, second only to nuclear energy. The plan is to develop in the next ten years the seven locations found by a team of the Commission of Volcanology to be rich geothermal reservoirs. This alternative source of energy, although clean and free (being supplied by nature itself) is not without problems and difficulties. The source might be indigenous but is it the ideal alternative for a developing country like the Philippines? At the moment, all the equipment and scientific manpower for the conversion of geothermal steam to electric power are imported, costing hundreds of million of dollars which are granted in the form of a loan. Can the government afford this? Geothermal energy, unlike oil, is nontransportable, so that full utilization of the power generated from the plant entails building an industrial complex in the vicinity. Is this taken into account in the long-range plan of the municipalities which are projected to be sites of geothermal power plants?

Another aspect to be considered in the utilization of geothermal energy in the Philippines is the size of the reservoir. How certain is it that the hot water or steam reservoir underneath the plant site will last for the minimum number of years needed to at least balance out the initial investment?

Most of the geothermal sites are in agricultural towns where practically no industry is developed as yet. It seems that the industry in those places is the power plant itself. In other words, the utilization of the power generated by the plant is not maximized yet at the present. An example is the

first geothermal power plant located in Tiwi, Albay, a province in the Bicol region southeastern part of Luzon Island. The plant costing a total of $21.67 million, was put into operation last February, 1979 and it is said that the power generated is more than enough to supply the needs of the Bicol area. There are plans of establishing in Legaspi City, the nearest city to the plant, an export processing zone. In this area, multinational companies put up factories for goods to be exported, produced at low cost since labor, energy and raw materials are cheap.

Another geothermal plant which is under development is the one in Tongonan, Leyte, one of the island provinces in Central Philippines. Again the projection is to provide electrical energy to an export processing zone under construction.

The third geothermal plant recently inaugurated is located about 100 kilometers from Manila. The total cost of the plant is $52.953 million. In the vicinity of the plant, factories of foreign firms are slowly sprouting.

The direct beneficiaries of the goethermal plants are the multinational firms and industries. It is true that 85% of the cost of the plants was supplied by a foreign firm too, in the form of machineries, engineers and scientists. But this is considered a national debt. The net gain still goes to the foreign investors; the Filipino people reap only the by products. Must progress and industrialization be like this?

THE DEVELOPING POTENTIAL FOR POLLUTION WITH GEOTHERMAL GROWTH

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EXTENDED ABSTRACT

Unfortunately, facts and experience have not supported the premise that geothermal energy is , and will be, innocent and with no threat of danger to our human environment. At the present, no major geothermal electric power development has escaped environmental challenges unscathed.

Environmentalists and some religious groups have traditionally regarded the sources of what is considered as geothermal energy to be entirely natural, automatically pure, and sacred.

Not too long ago, almost every nuclear public hearing was addressed with an argument for geothermal energy, saying, "Why isn't this public utility abandoning this evil atomic power concept and simply drilling a cost free hole right here?"

While fuel combustion plants are attacked for carbon dioxide releases, some geothermal power plants are releasing 500% of the coal or oil unit discharge of CO_2. Hydrogen sulfide (listed as poisonous gas by U.S.A. definition) discharges are reaching a 100 ton release per day level. Noise, atmospheric thermal, seismic, water vapor, scenic disturbances, subsidence, mercury, arsenic, and other deleterious discharges are joined by threats of radioactive gases.

An untouched thermal area might release water, gases, and minerals to the surface at a rate of about 435×10^3 kg per day, and when developed as a dry steam field for 1,000 megawatts, the release rate might be 218×10^6 kg per day. A flashed steam system may increase this surface release five fold per kilowatt.

The crux of the *geothermal growth related pollution* problem will be the additional releases at the earth's surface of *MANMADE* auantities resulting from an expandeded power program.

The thrust of this paper is that the over enthusiastic geothermal community and so called industry, along with governments should be facing facts before an outcry develops - "hands off" is neither enough or wise in today's public climate.

The threat is no longer nature's, but the plans of man.

THE INFLUENCE OF STANDOFF DISTANCE ON FRACTURING PATTERNS AND EFFECTS OF AN IMITATION HOT DRY ROCK BY IMPINGING OF WATER JET

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EXTENDED ABSTRACT

INTRODUCTION

As one of the new means of supplying energy, the development of geothermal energies stored in rocks in volcanoes or in hot dry rocks without hot water circulation system has been in progress. To extract the heat from such rocks, an artificial hot water circulation system must be created. Thus, it is necessary to develop methods for drilling and fracturing these hot dry rocks in order to provide paths for the water. The present object of our studies is to investigate the applicability of high speed water jets, whose fracturing ability is caused by the interactions between the thermal cracking and the hydraulic jet erosion, for drilling and fracturing of natural hot dry rocks. The papers of the first step of our studies were reported previously [1, 2, 3]. This paper deals with the experimental studies, which were carried out by using an imitation hot dry rock specimen instead of natural high temperature rocks, on the influence of standoff distance, L, namely the distance between the nozzle exit and the test surface of a specimen, the temperature of rock specimen and the value of physical properties of the rock specimen, on the fracturing pattern and efficiency.

MATERIALS AND METHODS

Rock specimens (75 mm O. D. and 150 mm in length) were made of a castable fire-resistant material. TABLE 1 shows their physical properties. Temperatures of the specimen, θ, were room temperature, 200, 400, 600, 800

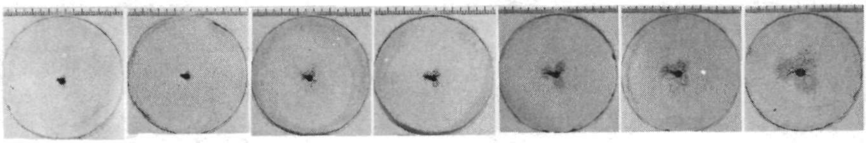
TABLE 1. PHYSICAL PROPERTIES OF THE SPECIMENS

Property	Temperature (°C)					
	15	200	400	600	800	1000
Apparent specific gravity (-)	1 67	1 66	1 62	1 58	1 57	1 53
True specific gravity (-)	2 66	2 68	2 74	2 83	2 80	2 73
Porosity (%)	37 2	38 0	40 9	44 2	44 0	43 9
Compression strength (Kgf/cm^2)	85 3	86 4	51 8	48 0	38 8	33 0
Tensile strength by R C T (Kgf/cm^2)	12 6	8 40	5 58	4 31	4 63	5 56
Youngs modulus ($10^4 Kgf/cm^2$)	2 70	1 79	1 07	0 776	0 484	0 563
Thermal conductivity (Kcal/mh•C)	1 05	0 680	0 526			

and 1000 °C. Water jet speed was kept constant at 84 m/s at nozzle exit (nozzle diameter, D_o, = 1.4 mm I. D.). Water was at room temperature. The nondimensional standoff distance, L/D_o, were taken as 20, 28.6, 40, 60, 80, 100, 150 and 200. Jet operation time was fixed at 10 seconds.

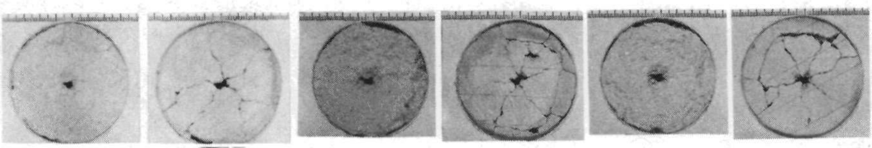
RESULTS AND CONCLUSION

Experimental results indicated that the fracturing patterns and effectivenesses varied characteristically with θ and L/D_o. On the surface of the specimen struck by the water jet, a hole-, a hole surrounded with eroded area-or a crater-shaped cavity was observed at a combinations of θ and L/D_o. Figures 1 and 2 show examples of the fracturing patterns in most and rare cases, respectively, at θ = 600 °C.



L/D_o= 20 28.6 40 60 100 150 200

Fig. 1. Typical examples of the fracturing patterns in most cases at different L/D_o in case of θ = 600 °C.



(a) (a-r.) L/D_o= 20 (b) (b-r.) L/D_o= 40 (c) (c-r.) L/D_o= 60

Fig. 2. Examples of the fracturing patterns in rare cases and the cracking patterns of the restored surface of the specimen at θ = 600 °C.

Fracturing effectivenesses, namely, the depth l (mm) and the volume v (cm^3) of cavity, increased with θ and reached the maximum at a temperature between 600 and 800 °C for the tested standoff distances. Curves showing the relations between the depth of cavity contributed by thermal cooling power, l_t, and θ were of N-shape having maximum and minimum at about 500 and about 800 °C, respectively, independent of the tested standoff distances as shown in Fig. 3. Curves showing the relations between l (or v) and L/D_o had a increasing tendency with increasing L/D_o. Figure 4 shows the relations between l/D_o and L/D_o at θ = 400 and 800 °C.

These results will be discussed from the viewpoint of the influence of standoff distance on normal jet cutting as well as characteristics of the heat transfer between hot surface and impinging water jets accompanied by boiling, and thermal stress induced in specimens.

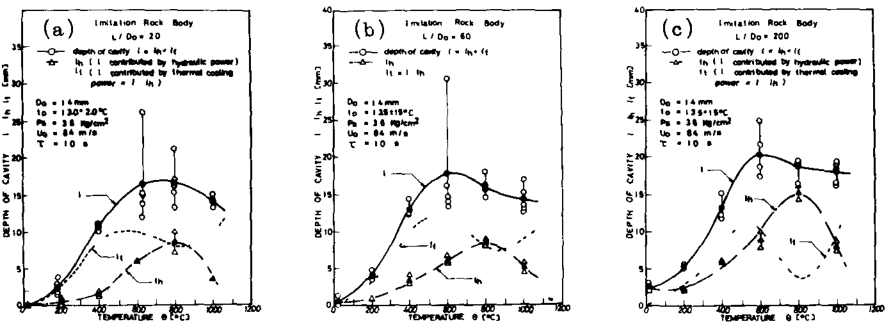


Fig. 3. Dependence of the depth of cavity fractured by the impinging water jet on the specimen temperature.

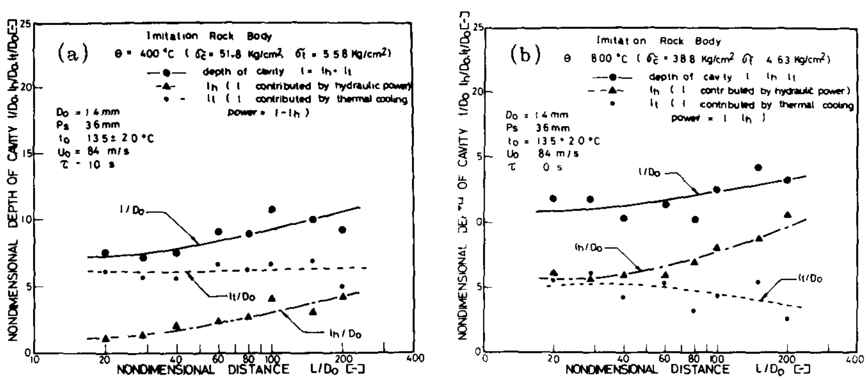


Fig. 4. Dependence of the nondimensional depth of cavity fractured by the impinging water jet on the nondimensional standoff distance at θ = 400 and 800 ^{o}C.

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GEOTHERMAL ENERGY AND BIOFUEL PRODUCTION IN AGRICULTURE

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EXTENDED ABSTRACT

Low temperature geothermal water can be used profitably for agricultural purposes, as an aid to production as well as for the processing of agricultural products.

Opportunities for integrated systems are especially appreciated as, because of the higher efficiency in energy use and the better economical behaviour, the multipurpose utilization of geothermal water is bound to become the predominant type of utilization.

Geothermal water being often available in sites where the population density is low, rural applications are realistically interesting, and relativelly small and self-sufficient energy systems are envisaged as the right reference collocation for low enthalpy geothermal resources employment. However, the use of this source for on-site power plants is not proved to be economically attractive.

Solar and wind energy can help in creating the desired self-sufficiency, but it must be said that at least an integration by means of fuel burning is practically unavoidable.

Fuel can be obtained from the agricultural wastes, or even a part of the agricultural production can be devoted to fuel production. It is here suggested that there is a kind of sinergy between geo-heat utilization and bio-fuel production.

The biogas output from anaerobic digestors can be stimulated introducing low temperature heat. For the production of alcohol from biomass, heat at amoderate temperature can be used. If the biomass production is assumed to be a target for the rural system under consideration, the possibility exists for geo-heat to be employed to increase the system productivity (e.q. by the means of soil heating).

There are at the end (accordingly with the fig. 1 scheme) three possible levels for geotehermal energy and biofuel production to be considered together.

Although then is not a definite and always good answer on the subject of convenience, and evaluation process is described apt to define the energetic and economic behaviours.

The possible macro-economic benefits on the part of the balance of payments are taken into account. Energetic, economic and social benefits are associated to the creation of effi-

cient energy centers, that will provide energy for the agricultural needs, from the industrial needs arising from agriculture-related processes and for the domestic and the leisure needs of socially advanced (neo-rural) communities.

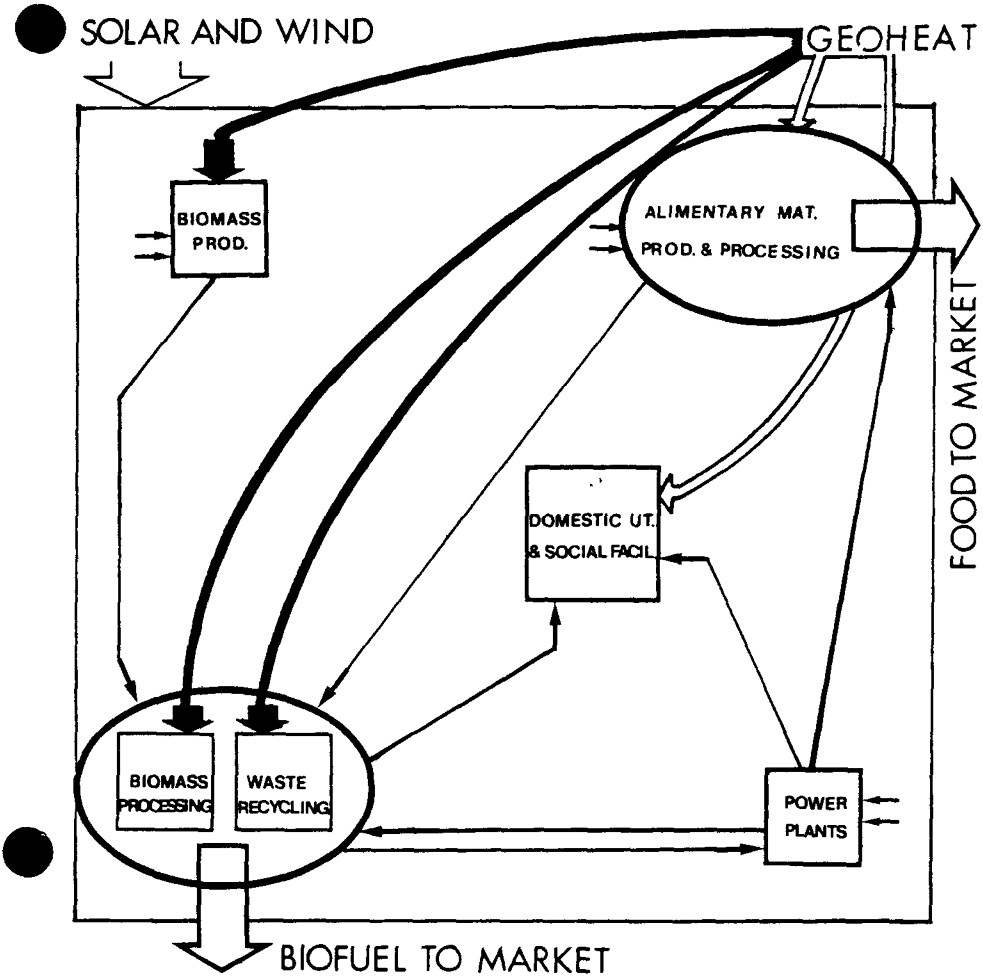

Fig. 1
Geo-heat possible applications in biofuel production systems

PLANNING ANALYSES FOR GEOTHERMAL DISTRICT HEATING

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EXTENDED ABSTRACT

INTRODUCTION

The competitiveness of geothermal district heating in comparison with conventional methods of energy supply for space and water heating and some industrial processes is influenced by many factors. Many factors tend to be site specific and to exhibit a wide variation among markets. A comprehensive planning assessment of the potential for geothermal district heating in any market should encompass life-cycle costing over a period of rising competitive fuel prices, address the expansion and financing of a district system over time, and include an overall optimization of system design.

We first describe our methodology for such analyses which is built around comprehensive detailed data sources, some of which were generated in the public domain for other purposes. These include Bureau of Census and Department of Energy surveys and U.S. weather station records. Our effort is distinguished by the depth and breadth of the data base and the ease with which any urban market can be analyzed.

A specific application for Salt Lake City, Utah, is also described. Marginal costing determines the optimal fraction of heat supplied by the base-load geothermal wells and transmission line and the fraction supplied by locally sited fossil-fired peaking furnaces. Heat storage is incorporated to lengthen well operating period. A financial analysis of constructing and operating the system over its expected lifetime is presented, and the primary factors which make district heat competitive with conventional heating systems and fuels are identified. This research is being carried out under the auspices of the U.S. Department of Energy under Contract No. EY-76-C-02-0016.

HEATING MARKET CHARACTERIZATION

Among the major difficulties in the United States for influencing levels and patterns of energy consumption through federal policy is the wide diversity in energy supply and demand characteristics exhibited among and within the various regions of the country. This is particularly apparent when the feasibility of a centralized alternative technology such as district heating is under consideration. For such a technology its competitiveness depends strongly on specific market characteristics and on local prices of conventional fuels.

Our elemental area is the census tract, for which published data allow estimation of residential heating demands, building retrofit requirements and existing fuel mix. Regional data on commercial floor space and employment are disaggregated among tracts by two methods which lead to upper and lower bound estimates of commercial heating demand for each tract. Validation of demand estimates and fuel mix can be done on urban, regional, or national levels.

Peak and annual demands for space and water heat are estimated for highly detailed building categories in each tract. These categories are based on building size, dwelling unit size, building use (for commercial structures), and heating system type. Cost of building retrofit to district heat and cost of conventional fuels is incorporated in order to define the extent of the market for district heat; i.e., the numbers and types of buildings that could economically be converted. Thus, potential heat demands for district service are established from the computerized data base for all census tracts in the urban market under analysis.

DESIGN AND COSTING OF HEAT SUPPLY AND THE DISTRICT PIPING SYSTEM

Several contiguous tracts are aggregated to form a heating zone which becomes the fundamental unit for pipe system design and economic analyses. Estimated market is reflected in pipe system designs. Pipe lengths, diameters, and installation costs are assigned on the basis of peak demand, service temperature, local labor and materials costs, and statistical relations between population density, water main length requirements, and water and gas main installation costs.

For simplicity, heating zones are assumed to be square, and the computer designs the pipe system from the extremes toward the center in a simple rectangular layout. Optimized diameters and flow rates are calculated for each heating zone using parameterized supply and return temperatures. Conductive losses and pumping power are accounted for at each step of the design. The total number and length of blocks in each heating zone is assigned from a data base established from statistical correlations between street density and land use intensity in a cross section of U.S. cities. Peak power requirement serves as the design point. Costing is done on a zone by zone basis so that cost to benefit ratios can be used to rank zones in order of payoff and to determine the optimal system size. At present interconnection of heating zones by the subtransmission network is done by hand, but we anticipate that this calculation can be computerized.

A curve of probability density for heat demand as a function of time is constructed for each market from 30 year average daily temperature data. Thermal and physical characteristics of known geothermal resources are correlated to urban markets to ascertain transmission distances and cost of reservoir development.

A sufficient amount of short term storage capacity is included to smooth out disparity between instantaneous supply and demand. Finally, heat source allocation is made via a marginal cost analysis which compares the incremental cost of adding one geothermal well and increasing the transmission line capacity and storage capacity concomitantly to the cost of supplying the increment of heat, as determined by the demand load curve, via a fossil-fired boiler. This analysis yields the optimum power demand level for the peaking source. The area under the load curve below this peaking level yields the average annual heat delivered from the geothermal resource. The average heat production cost is obtained as a weighted average of the costs for resource produced heat and boiler produced heat and boiler produced heat.

ECONOMIC ANALYSIS FOR SALT LAKE CITY

The methodology described herein has been used to develop and cost a systems-type design for geothermal district heating in Salt Lake City, Utah. Annual sales for an optimally sized system are 5.1 x 10^{15} J. Approximately 92% of the heat sold is from geothermal wells with the remainder supplied by fossil-fired peaking boilers.

Implementation of the system is spread over eleven years with initial heat sales beginning in the third year. District heat is priced competitively with natural gas after allowance for retrofit costs by building owners of up to $58/kW on an annualized base. In the scenario analyzed it is assumed that the residential price for natural gas increases in accordance with recent trends, from \$1.71/10^6 Btu in 1979 to \$4.30/10^6 Btu in 1990. Assuming a real cost of capital of 6 1/2%, a discounted present value analysis of expenses and revenues shows that a system having a lifetime of 30 years is economically viable. Analysis of annual revenues and expenses shows that net revenue would become positive in the eleventh year. Thus, under what is considered to be a reasonable price projection for natural gas, a municipally financed geothermal district heating system for Salt Lake City appears to be economically viable.

THE GEOTHERMAL POWER PLANT OF PUCHULDIZA
CHILE, I. REGION

by

P. TRUJILLO - R. BRAVO AND T. SOLAR

In September 1978, the professionals of the Comité Geotérmic CORFO, runned for the first time in Chile and in South America, an experimental power plant moved by the steam discharged of Well N°2 from the Geothermal field of Puchuldiza.

The main purpose of this experimental unit, is to specify perfomances, corrosion problems and the quantity an quality of the deposits of solids in separators, pipe lines, and eventualy in the turbine.

The Geothermal power plant, consists in 3 main units:

- a steam-water separator, by wich the fluid erogated by the well is separated in two phases : water and almost dry steam.
- a one stage turbine, that at 3000 RPM. car deliver 150 KW nominal
- a threephase generator of 380 volts and 50 c/s , that is able to deliver a maximun of 45 KW at 1500 RPM.

The test runs up to present, have given good results. The real power obtained has been of 10 KW., working with an inlet pressur to the turbine of 35 psig, and discharging to the atmosphere (8,6 psi In this way Chile has been the first country in South America that ha produced electricity by using the geothermal resources. This is an important step in the development of this important energy source of Chile.

THE COAXIAL GEOTHERMAL WELL FOR HEATING AND COOLING LARGE BUILDINGS

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EXTENDED ABSTRACT

Space heating and cooling demands 30% of our annual energy consumption of 27 quads. It also accounts for both the winter and summer peaks in electrical power generation, and in winter represents the greatest drain upon our most precious unrecoverable resource, natural gas.

Yet all the cool air needed for summer is available every winter, and all the heat needed for winter is available every summer; so that 30% of our annual energy demand could be eliminated if this summer-winter transfer were possible.

This paper proposes doing this by use of natural water circulation in a cased geothermal well with a coaxial inner pipe.

Based on a research program on drilled geothermal power generation, it is shown that such a 10,000-foot well (3 km) would penetrate strata in excess of 80°C at the bottom.

Further results of this research, assuming average rock density of 2.70 g/cc, and thermal diffusivity of .013 cm^2/sec, show that the lower half of such a well, costing about $500,000, could completely supply the winter heating needs of 50,000 square feet of modern well-insulated apartments or office building in a 4000 degree-day climate, by natural circulation of cooled water down the outer annulus, returning hot water up the core.

The same circulation would pre-cool the upper strata of the well which would then be applied to cool the same facilities in summer, by circulating water in the reverse direction in the upper half of the well only.

For more severe winter climate either a deeper well or heat pump could be used, whichever incremental investment shows the better return.

In either case, the well would represent a capital investment of less than 25% of the buildings being heated and cooled, with no fuel cost and almost no maintenance cost for the life of the building.

MEXICO'S SUCCESSFUL GEOTHERMAL POWER PLANT

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EXTENDED ABSTRACT

INTRODUCTION

Flashed-steam geothermal power plant technology well established in Mexico, New Zealand, Japan and emerging in several other countries is now producing more than 600 MW of electricity. Development of flashed steam systems has lagged in the United States due to the lack of operational experience and data on these types of power plants. Reliability and maintenance data from one of the plants now operating in Mexico would be beneficial in assessing the electric utility position relative to commitments to geothermal power from liquid dominated systems.

HISTORY

Most of the known geothermal fields are of the liquid-dominated type - producing a mixture of hot brines and steam. Despite the larger estimated total heat content, 715 x 10^{18} calories versus 26 x 10^{18} calories, more geothermal electric power at the present time is generated from vapor dominated rather than liquid-dominated systems. The development of geothermal power from liquid-dominated fields is technically more difficult than from vapor-dominated systems principally because: (A) greater masses of fluids must be produced to generate a given amount of electrical energy; (B) corrosion of well casing and piping may be excessive; (C) precipitation of minerals from the brines may be considerable; (D) large pore pressure drops in the reservoir rock may result in subsidence at the ground surface.

A significant number of the high temperature (T 150 C) geothermal liquid-dominated systems in North America are located in the same geologic province (Salton Sea-Sea of Cortez Trough). Early exploration efforts in the Cerro Prieto area began in 1959 and extensive information has been collected by Mexican scientists and engineers.

The liquid-dominated field of Cerro Prieto began generating 75 MW of electric power in 1973. The increasing level of activity in utilizing the Cerro Prieto field for electric production, plus the vast amount of information collected by Mexican engineers, makes this project an ideal subject for a program of technology transfer.

An official 5-year agreement between Mexico and the USA was signed on 21 July 1977. Many tasks covered in the agreement include geologic, hydrogeologic, geophysical, geochemical, subsidence, and reservoir engineering studies.

GENERAL DESCRIPTION

The Cerro Prieto geothermal field presents hydrothermal surface manifestations in an area of about 30 square kilometers where the production zone is located. More than 50 deep wells have been drilled to a depth ranging from 700 meters to 2,000 meters.

As water ascends through the production well casing, it partially flashes into vapor, flowing as a two-phase mixture with 20%-40% vapor. The two-phase mixture passes through a centrifugal Webre type separator. The steam is sent to the power plant and the separated water flows to an evaporating pond. Between 13 and 16 wells are needed to maintain full electrical output of Units 1 & 2 rated at 37.5 MW each.

AVAILABLE TECHNICAL INFORMATION

The commercial exploitation of the Cerro Prieto geothermal resource attracted a great deal of attention. There have been numerous publications about various phases of development, such as the exploration and drilling of wells and the power plant design and operation. The preponderance of the published information concerns the wells and geothermal reservoir.

WELL COMPLETION AND DEVELOPMENT AT CERRO PRIETO

Fifty-five wells have been drilled in the Cerro Prieto geothermal field of which 42 are production wells and 13 exploratory wells. These wells were drilled in six stages over a 15-year period, with some modifications in completion methods, both in diameters and casing characteristics.

OPERATION OF THE WELLS

A typical production well is built with a 406 mm (16 in) diameter anchoring casing extending to a depth of 150-300 meters; 298 mm (11.75 in) diameter conducting casing to depth of 700-1,100 meters and a 192 mm (7.625 in) diameter production casing to a depth of 1,300-2,000 meters.

The high solids content of the fluid flowing from the wells contribute to scaling and corrosion. The mean life of the Cerro Prieto geothermal wells is estimated to be 15 years. Several of the production wells are 14 years old, still in good condition, delivering steam to the plant.

PIPE LINES CARRYING STEAM TO PLANT

The piping system for gathering steam to use in Units 1 and 2 consists of four (4) branches. The connection pipe between each well and one of the branches varies between 30 cm (12 in) and 41 cm (16 in). The diameter depends upon the production capability of the well. An average of 5 wells are connected to each branch line.

The branches vary in diameter from 46 cm (18 in) to 86 cm (34 in) as they progress to the power plant. We have not encountered many operation or maintenance problems with the steam gathering/conduction system.

POWER PLANT CHARACTERISTICS

Principal components of a generating unit are as follows:

<u>Turbo-Generator</u>

Single cylinder, double flow, impulse condensing turbine; 5.3 Kg/cm^2 inlet steam temperature, 89 mm Hg exhaust pressure, 508 mm maximum blade length, 284,450 Kg/hr flow at nominal capacity 35,500 kw; generator 44,200 KVA, 0.85 PF, hydrogen cooled 2 Kg/cm^2.

<u>Barometric Condenser</u>

Vertical, cylinder, jet type-6.7 m diameter, 26.5 m height; tail pipe-2.0 m diameter 13.9 m height; steam inlet-3.6 m diameter; shell low carbon steel with epoxy resin overlay; trays SS-AISI 304 L. The non-condensible gases are removed by a steam jet ejector with barometric type inter and after cooler. Operating steam pressure 5.3 Kg/cm$_2$, steam use 24200 Kg/hr.

<u>Cooling Tower</u>

12 cell design, 146 x 25 x 15 m, to cool 27,300 m^3/hr water in a range of 16 C. Tower is treated wood type with induced draft and cross flow of air.

POWER PLANT OPERATION

Unit No. 2 began commercial power production in April 1973 with Unit No. 1 following in September 1973. The operation of these two units has continued virtually uninterrupted since entering commercial service with only scheduled annual shutdowns of the turbine-generators which have not shown any major problems.

Annual plant factor has increased each year: 1973 - 0.54; 1974 - 0.677; 1975 - 0.788; 1976 - 0.878; 1977 - 0.904; 1978 - 0.91. The plant factor is much better than a fossil fuel steam electric station because the steam production has a multiple supply (wells) rather than a single supply (boiler) as we find in unit boiler-turbo generator power plant designs.

Unit No. 3 began operation in February 1979 with Unit No. 4 following in March. Plant capability is now 150,000 KWe.

SESSION 3E

HYDROGEN ENERGY II

MICROCAVITY HYDROGEN STORAGE

BY

R.J. Teitel*, T.M. Henderson*, J. Powers+ and J.E. Luderer*

The development of economical, efficient and safe handling technology for the production, distribution and consumption of hydrogen is essential to many future power, transportation and chemical industrial applications. A safe and economical means of storing hydrogen is a critical element in the utilization of hydrogen in all of its applications. DOE and its predecessor organization, ERDA, have provided a continuing research program in this area. Three basic types of hydrogen storage systems are being studied and evaluated extensively. They include (1) high pressure gas storage in large tanks or natural vessels, (2) storage of liquid hydrogen at cryogenic temperatures, and (3) chemical storage. The first two types of storage are well known and utilize established technology. Metal hydride storage systems have been the most promising of the chemical storage systems currently under development.

Recently, a new approach to high pressure gas storage has been introduced by ROBERT J. TEITEL ASSOCIATES, (the microcavity system). This concept employs structures which have micron sized (10-100 μm), thin-walled (1-10 μm), closed cavities. Storage is accomplished by filling the cavities with hydrogen. The cavities are either filled or emptied of hydrogen by diffusing the hydrogen through the walls of the cavities at elevated temperatures by regulating the surrounding hydrogen pressure. The storage structure, currently being considered, is a bed of hollow, glass microspheres. Microspheres made of plastics, metals, ceramics and carbon are also available and are being considered as candidate alternative microcavity structures. Microspheres can be utilized either in the form of a free flowing powder or a sintered mass.

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A preliminary engineering evaluation of the automotive application of micro-cavity systems has been conducted by ROBERT J. TEITEL ASSOCIATES under the auspices of the DOE using available data and without "in-depth" optimization.

A metal hydride bed was used to absorb excess hydrogen during shut down and room-temperature storage. This bed also supplied hydrogen during start-up. In this way, the combined system compromised some of the attributes and disadvantages of each.

The evaluation indicated that the microcavity system is, by far, lighter and less costly than an advanced hydride storage system meeting the same set of specifications. Since the same advanced hydride chemical energy storage system is competitive with advanced battery storage systems, it follows that the microcavity system is also competitive with battery storage systems. This report will present the results of the evaluation study. Economics, power utilization and performance of the microcavity hydrogen storage system will be discussed in detail.

Cup

BULK HYDROGEN STORAGE USING METAL HYDRIDES*

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EXTENDED ABSTRACT

INTRODUCTION

The content of this paper is based on experience with TiFe-based hydrides, such as $FeTiH_x$ and $TiFe_{0.9}Mn_{0.1}H_x$, used in work related to bulk hydrogen storage [1,2]. In comparison with gas stored at high pressure in steel cylinders, and with liquid hydrogen stored at very low temperature in insulated containers, decomposable hydrides provide a solid-particle storage medium which functions at ordinary temperatures and modest pressures. This trade-off in storage conditions requires a container provided with a heat exchanger and a filter/distributor. TiFe-based hydrides characteristically function at temperatures above 0°C, and can be fully chargd with hydrogen at 500 psi. The heat thus evolved is removed by passing cold water through the heat exchanger. Likewise the heat required for hydrogen discharge is supplied by hot water. Under dynamic conditions, the useful storage capacity of TiFe-based hydrides is 1.2-1.5 wt %. High-capacity, long-life performance has been demonstrated using 99.999+% hydrogen, which is attainable from the electrolytic grade. When impurities such as air or moisture cause poisoning, the loss of capacity can be restored by heating and evacuation of the hydride. These properties suggest the use of TiFe-based hydrides for applications where weight is not a critical factor, and where there is a source of waste heat for discharging the hydrogen. Hydrogen transfer times are typically in the 5 to 10-hour range.

APPLICATIONS

The first bulk-storage use suggested for $FeTiH_x$ was in peak shaving for an electric utility [3]. In this concept off-peak or spinning-reserve power is used to produce electrolytic hydrogen for storage as a TiFe-based hydride; recovery of the stored energy consists of reacting released hydrogen with air in a fuel cell, thereby regenerating electric power. This concept was tested at Public Service Electric and Gas Company (PSE&G) of New Jersey using a reservoir of 12-lb-hydrogen capacity built at Brookhaven National Laboratory (BNL) [4,5]. Because the overall efficiency was projected to be only 40-50%, mainly due to low efficiency of the fuel cell, the concept was not attractive [6].

*Research done under the auspices of the U.S. Department of Energy.

A reservoir of 55-lb-hydrogen capacity is being tested at the Hydrogen Homestead constructed by Billings Energy Corp. (BEC) in Provo, Utah [7] is intended to supply fuel for cooking, some heating, and for powering a garden tractor. Although the use of electrolytic hydrogen was initially proposed, plans now call for using coal-derived hydrogen. The 38-in.-diam. x 49-in.-high vessel is made of carbon steel and has an external coil wrap at its midsection for the heat exchanger.

TiFe-based hydrides might also be used where compact energy storage is required for an indefinite time. Unlike batteries, there is no deterioration with time; so the hydride could serve in an emergency power supply system, or provide fuel directly. The heat required for hydrogen discharge would have to be provided by the end-use device or another source.

DESIGN FEATURES

In addition to satisfying the thermal requirements of hydrogen transfer, and dealing with fine particles, a means of accommodating hydride expansion in the reservoir has to be provided. The 10% volume change during cycling can cause vessel bulging in beds more than several inches deep, because the particles gradually settle and become tightly packed [8]. Small-scale tests at BNL have shown that a high-flow pulse through porous tubes at the bed bottom will loosen the particles by fluidization [9]. Thus large-diameter vessels require this additional feature. Periodic loosening is required, and it is best done prior to charging because the greatest pressure differential is available then. Contrary experience on hydride expansion has been obtained at BEC in cyclic tests [7]. The lack of detectable expansion was attributed to activation (hydriding for the first time) in a separate vessel (and subsequent physical transfer); however, it is also possible that the use of a heavy-wall vessel could have forced the hydride to expand upward toward the free surface, or that the change in hydride composition was restricted by the conditions of the experiment. Packaging the hydride in horizontal tubes or the use of shallow trays can also be used to permit free expansion of the hydride without the use of auxiliary devices.

Two basic styles of heat exchangers using water are possible [1]. The first is a tubular type immersed in the hydride bed, and the second has hydride tubes immersed in water. The PSE&G reservoir is an example of the former, but so far only a single-tube unit having hydride in the tube has been tested at BNL. In the latter case the tube is the pressure vessel, and an array of horizontal tubes would be supported in a water tank. Although this arrangement requires a diameter increase of nearly 20%, there is no large pressure vessel, and it is possible to repair a leak by removing the faulty tube.

IMPROVED DESIGN

A 2 ft-diam. x 10-ft-long reservoir having a nominal hydrogen capacity of 50 lb was recently designed and constructed by Foster Wheeler Energy Corp. under contract to BNL. It has a U-tube heat exchanger, and two features for dealing with hydride expansion. A group of tubes having porous-metal windows is provided for loosening the bed, and a collapsible center body absorbs unrelieved expansion, thereby protecting the vessel. The center body is a vertical, longitudinal member 2-in. wide, and is provided with internal springs for restoring its shape. The reservoir will be tested at BNL's Hydrogen-Technology Advanced-Component Test System (HYTACTS) following completion of system check-out and the safety review [9]. Observations will be made on vessel expansion, bed loosening and on times of sustained hydrogen transfer. Design details and available test results will be provided in the formal paper.

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DEVELOPMENT OF SOLAR-HYDROGEN SYSTEMS USING METAL HYDRIDES

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EXTENDED ABSTRACT

INTRODUCTION

Before the end of this century, oil will have ceased to be the prime energy source for our industrial society. The need for energy will continue to grow and society will become increasingly dependent on renewable energy sources such as the sun and the wind.

Solar energy has been hailed by many as the answer to our energy crisis. However, the fact that it is a clean, unlimited energy source does not overcome the main problem of solar energy, namely, that it delivers energy in a very dilute form and intermittently. To overcome these deficiencies, better ways of collecting and storing solar energy are urgently needed. To date, photovoltaic, photochemical, photoelectrochemical conversion methods have been inefficient and much too costly for widespread application. However, as oil producers continue to extract higher profits from their remaining fossil fuel reserves and as further advances in solar conversion technology are realized, the time is rapidly approaching when solar-derived energy will be economically competitive with fossil fuel.

SOLAR-HYDROGEN OPTIONS AND THE ROLE OF METAL HYDRIDES

Table I lists the solar energy conversion options potentially useful for hydrogen production. By whatever means hydrogen is produced, it must be collected, stored, transported, distributed and finally utilized as a synthetic fuel, energy carrier or chemical feedstock. Metal hydrides offer an attractive economic means of performing these functions. The attractiveness of metal hydrides stems from their high hydrogen density per unit volume and their ability to release and absorb thermal energy during hydriding and dehydriding reactions, respectively. The extraordinary range of hydrides now available offers a number of interesting, unique applications to the solar-hydrogen energy concept. This paper reviews some of the more important applications.

A potentially attractive application is the use of low-grade solar heat from solar ponds to drive hydride compressors and power large electrolysis plants. This concept could be applied on a large scale, with hydrogen being transmitted by pipeline to major consumption sites, or could be applied on a small scale to produce hydrogen for local consumption.

Hydrides could also be used for temporary storage of hydrogen for stationary and vehicular applications. Hydride storage systems could be readily interfaced with any of the solar-hydrogen options listed in Table I.

In addition to using hydrides for storage and utilizing hydrogen as a fuel, there have been many recent developments in hydride systems which use hydrogen as a working fluid. Such systems would be particularly attractive for interfacing with solar-derived hydrogen since, for the most part, they can operate on low-grade solar heat to provide heat-pumping action and refrigeration. Because these systems would utilize only a small fraction of the solar-derived hydrogen, they would greatly improve the overall efficiency of the conversion process by providing supplemental power, heating and cooling which gaseous or liquid hydrogen systems could not provide.

In this paper, some advanced solar-hydride concepts will be described and specific comparisons will be made with alternative approaches.

TABLE I

SOME SOLAR-TO-HYDROGEN CONVERSION OPTIONS

Sunlight-Water:	photosynthetic photocatalytic photochemical
Sunlight-Electricity-Water:	electrolysis
Sunlight-Heat-Water:	thermal splitting thermochemical

EFFICIENCY OF HYDROGEN COMPRESSION BY MEANS OF HYDRIDES

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EXTENDED ABSTRACT

Several devices, such as water pumps, heat pumps and compressors, have been proposed which all share a common feature; namely, the use of heat in conjunction with a reversible hydride to compress hydrogen. Several factors will determine the technical and economic viability of these devices. One of these factors is the thermal efficiency of hydride compressors. There are two rather different ways to evaluate the thermal efficiency of a hydride based hydrogen compressor. The first of these is what may be referred to as the first law efficiency; namely, the ratio of the theoretical work of compression to the total heat input to the device. The other way to look at hydride compressor efficiencies may be referred to as the second law efficiency; namely, the ratio of the theoretical work of compression to the maximum work obtainable from an ideal device operating between the temperature of the heat source, T_2, and the heat sink, T_1.

This paper discusses the maximum efficiencies obtainable for hydride compressors as a function of the temperature of the heat source, T_2, the temperature of the heat sink, T_1, and X which is the ratio $C_p/\Delta H$ where C_p is the system heat capacity (hydride plus container) per mole of hydrogen capacity and ΔH is the heat of absorption per mole of hydrogen.

For an idealized hydride based hydrogen compressor, it can be shown that the first law compression efficiency, η_1, is given by

$$\eta_1 = \Delta T/(T_1 + \Delta T)(1 + X\Delta T) \qquad (1)$$

where $\Delta T = T_2 - T_1$. The maximum value of this first law efficiency, η_{1m}, occurs when

$$\Delta T = (T_1/X)^{1/2} \qquad (2)$$

and is given by

$$\eta_{1m} = (T_1/X)^{\frac{1}{2}}/[T_1 + (T_1/X)^{\frac{1}{2}}][1 + (T_1X)^{\frac{1}{2}}] \qquad (3)$$

Thus, for a given system, the value of η_1 will initially increase with an increase in ΔT, reaching a maximum value when $\Delta T = (T_1/X)^{\frac{1}{2}}$. Any further increase in ΔT will then result in a decrease in η_1 with $\eta_1 \to 0$ as $\Delta T \to \infty$. As $X \to 0$ the maximum value of η_1 will approach 1 as $\Delta T \to \infty$. As X increased from zero the maximum obtainable efficiency, η_{1m} will decrease and this maximum will occur at decreasing values of ΔT.

The second law efficiency, η_2, is given by

$$\eta_2 = \eta_1/\eta_C \qquad (4)$$

where η_1 is the first law efficiency discussed above and η_C is the maximum obtainable efficiency of an ideal heat engine operating between a heat source at a temperature T_2 and a heat sink at a temperature T_1 and is given by

$$\eta_C = (T_2-T_1)/T_2 = \Delta T/(T_1 + \Delta T) \qquad (5)$$

and

$$\eta_2 = 1/(1 + X\Delta T) \qquad (6)$$

Thus, as ΔT increases from zero, the first law efficiency starts at zero and increases to a maximum when $\Delta T = (T_1/X)^{\frac{1}{2}}$ then decreases as ΔT is increased further. The second law efficiency in contrast starts at 1 when $\Delta T = 0$ and decreases toward zero as ΔT is increased. Hence, as ΔT increased from zero up to a value given by $\Delta T = (T_1/X)^{\frac{1}{2}}$ a hydride compressor makes increasingly more efficient use of the thermal energy supplied while at the same time becoming increasingly less efficient as compared to an ideal heat engine operating over the same ΔT.

HYDRIDE BEDS: THERMAL TRANSPORT ENHANCEMENT*

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EXTENDED ABSTRACT

INTRODUCTION

The idea that hydrogen will be used on a large scale as an energy carrier in this country within fifty years is becoming fairly well accepted by at least the scientific community. The use of hydrogen presupposes the need for storage in a form that is safe, economically viable, and both environmentally and esthetically acceptable. Hydrogen, as well as most other gases, has traditionally been stored and transported as a compressed gas at pressures approaching 3000 psi in very heavy-walled steel cylinders. Hydrogen in liquid form, although orders of magnitude lighter in weight, is probably not a viable option because of safety and economic considerations [1]. Metal hydride storage is a proven technology which may also have, because of their inherently high heats of reaction, application in the areas of chemical compressors and heat pumps, as well as the hydrogen storage area [2-4].

Although BNL has taken an active role in the evaluation of many hydrogen storage options, the "in-house" effort has been generally directed toward the development of the metal hydride storage concept. In the engineering area, where our efforts have focused primarily on iron-titanium hydride, solutions are being sought to the engineering problems presented by the characteristics inherent to this system. The fact that metal hydrides become extremely fragile, due to cracking upon hydrogen activation, causes the material to crumble into fine particles whenever the bed is disturbed. In larger systems (where the bed depth is greater than a "not-yet-determined" critical value) the forces generated by the expanding alloy as it absorbs the hydrogen greatly aggravate the attrition problem. Poor thermal conductivity and fairly high pressure drops are experienced as the particles get very small after an extended number of charge/discharge cycles [5]. This will be an important consideration in fast-fluid flow-rate systems such as for automotive applications and for the chemical compressor application where even higher flow rates are anticipated. The poor thermal conductivity of the bed as a result of the many contact resistances is one of the problems on which BNL has applied its energies.

*Research performed under the auspices of the U.S. Department of Energy.

HEAT TRANSFER ENHANCEMENT TEST PROGRAM

The addition of small amounts of high conductivity material to the hydride bed in an attempt to enhance the heat transfer was investigated. It was decided to use an approach that would involve the transient thermal transfer mode since the results would be more representative of actual operating conditions. The experimental apparatus included a thin-walled (2.45" I.D. x .095" wall) cylindrical copper vessel 11 1/4 inches long, rated at 200 psia, and flanged at both ends. Two temperature-controlled baths (30° and 80°C) were used to provide the constant temperature environment at the outside wall of the test vessel. Three shielded thermocouples were positioned at the vessel center line with longitudinal displacements of 2.3 inches between the hot junctions. The two extreme thermocouples were provided only to insure that end effects were minimal and heat flow was axial. All the data presented in this report were measured by the center thermocouple. For each set of experiments the test vessel was assembled, filled with hydride (2365 grams) and machine packed by raising and dropping the vessel with its holder (total weight 25 lb) a distance of 0.75 inches at the rate of 1 1/2 taps per second for 30 minutes (∿2700 taps). This procedure was adopted to eliminate variances in the bed's void fraction which was computed using bed height measurements taken through holes in the top flange. Each heating run was started by causing all three thermocouples in the test apparatus to approach the bath temperatures (30°C) to within 0.2°C.

The test vessel was then removed and immediately immersed in the high temperature (80°C) bath and the data measurement started. The rate at which the data were recorded was chosen so as to provide a minimum of fifty data points for each run. Generally each run was repeated three times and the results were extremely reproducible. Three configurations were used: 1) no enhancement, 2365 g packed bed of -30+80 mesh deactivated FeTi hydride; 2) the same bed with 5 wt % of the hydride removed and replaced with an equal weight of copper in the form of a knitted mesh [6]; 3) the same bed with 5.6% of aluminum in the form of a reticulated foam [7]. Each of these configurations was tested with 150 μm, 1.0 psia and 200 psia hydrogen pressure in the test vessel. The data were treated as given by R. V. Churchill in his "Operational Mathematics" [8].

The results are listed in Table I. Four very definite conclusions may be drawn from these results:

- The greatest contribution to the thermal transport of the system is made by the hydrogen gas.
- The form of the enhancement material is a more important consideration than the conductivity of the material.

- The addition of 5.6% aluminum foam enhances the effective thermal conductivity of a hydride bed at 200 psi hydrogen by a factor of 2.6.

- This technique is a very convenient and quick method of screening new heat transfer enhancement concepts.

The thermal conductivity values for the no-enhancement runs compared favorably with measurements reported by Reilly [9] and Yu [10] being slightly higher than Reilly's but lower than Yu's. Both of their results were made using essentially the same bed material but an entirely different experimental technique.

TABLE I

HEAT TRANSFER ENHANCEMENT OF BEDS OF $FeTiH_x$

Run No.	H_2 Press.	ε	E	α	k	t_{55}
3A	150μm	0.490	None	0.000754	0.0189	167
1A-CE		0.497	5% Cu	0.00235	0.058	53.5
1G-AE		0.545	5.6% Al	0.00494	0.109	25.5
5A	1 psia	0.490	None	0.0148	0.371	8.5
2A-CE		0.497	5% Cu	0.159	0.394	7.9
2A-AE		0.545	5.6% Al	0.0829	1.834	1.52
8A	200 psia	0.513	None	0.0396	0.954	3.2
3A-CE		0.497	5% Cu	0.0362	0.902	3.5
3A-AE		0.545	5.6% Al	0.1122	2.497	1.12

ε - Void Fraction
E - Enhancement Material
α - Thermal Diffusivity
k - Effective Thermal Conductivity Btu/hr-ft-°F
t_{55} - Half Time Minutes

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7. Aluminum foam manufactured by Energy Research & Generation, Inc., Oakland, California. 140 Grams of 10 pore per inch material with a measured density of 5.8% and 6.1% was added to the bed for a total aluminum density of 5.6%.

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ACKNOWLEDGMENTS

The construction and operation of the thermal conductivity enhancement apparatus as well as the data tabulation and plotting was performed by Win Lewis whose expertise and cooperation were invaluable.

Gry

ENHANCEMENT OF LOW GRADE HEAT VIA THE HYCSOS CHEMICAL HEAT PUMP*

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EXTENDED ABSTRACT

The Argonne HYCSOS system [1-4] is a thermally driven chemical heat pump based on two metal hydrides with different free energies of formation that functions in heating, cooling and energy conversion modes. Hydrogen is transferred by means of thermal gradients from one hydride bed to another and the heat released on hydride formation or absorbed on hydride decomposition is available for heating or cooling purposes. With three beds of the same hydride cycling between a higher temperature and a lower one, a continuous supply of high pressure hydrogen can be generated, do useful work in an expansion engine-dynamo unit supplying electricity and then be absorbed on the alloy at a lower temperature.

An interesting mode of HYCSOS operation is made feasible by the recent development of a series of ternary alloys whose hydrogen decomposition pressures at a given temperature can be varied by several orders of magnitude by substitution of Group III A or IV A elements for Ni. By proper choice of pairs of alloys with properties suitable for the available temperature regime, low grade solar energy, such as can be obtained from inexpensive flat plate collectors in northern areas with low levels of insolation, can be enhanced to provide domestic hot water. In particular, the substitution of aluminum for one nickel atom in the $LaNi_5$ class of alloys reduces the dissociation pressure at room temperature from approximately 2 atmospheres to about 10^{-3} atmospheres. Within experimental error, a 0.1 change in "x" in the aluminum content of $LaNi_{5-x}Al_x$, changes the heat of formation by 0.5 kcal/mole H_2 [5]. Measurements on well annealed samples show entropy changes over a wide composition range to be virtually constant [6]. Similar substitution of aluminum for nickel in mishmetal nickel alloy, in addition, substantially reduces the unacceptably high hysteresis and permits the use of this much less expensive material [7].

Thermodynamic considerations of hydride heat pumps [8] show greatest heat pump efficiency, the heat pump able to pump from the lowest temperature, when the entropy of the hydriding reaction for the two alloys is the same. To cycle between a

solar collector temperature of 40°C and producing a high temperature of 75°C, a ratio of 1.11 is suggested for the enthalpy of hydride formation for two alloys having the same entropy. Hydrogen could be returned from the second hydride at 40°C to the original alloy at a temperature as high as 4°C. Although the alloys currently being used in the HYCSOS system are not an optimum pair for this temperature regime, five moles of hydrogen (equivalent to 38 kcal) was transferred from the less stable alloy hydride at 40°C and absorbed as the more stable hydride at 66°C. Temperatures as high as 80°C could have been achieved, but 66°C is considered a safe maximum for domestic hot water use. To return the hydrogen to the first alloy at 4°C would require the more stable hydride at 60° rather than the 40°C assumed available from the solar collector. However, using $LaNi_{4.8}Al_{0.2}$ to form the more stable hydride would permit the return of hydrogen at 40°C to the $LaNi_5$ as the less stable hydride at 4°C.

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FIXED SITE HYDROGEN STORAGE: II. COMPARISON OF TECHNOLIGIES AND ECONOMICS

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EXTENDED ABSTRACT

A companion study** addressed the national problem of bulk storage of hydrogen (location, scale and cost) in a scenario of widespread usage. Small users may desire to store hydrogen, provided compatible, affordable storage modes are available. In this study, presently available and some possible future technologies are studied with the intent of identifying the minimum cost storage technique for various combinations of quantity, cycling frequency and parasitic energy costs. Peg points of 10 MwHr electric equivalent (34 MBTU), and a least-cost size scale are identified for each technology.

Three basic storage forms are considered: pressurized gas, cryogenic liquid and hydride; a fourth form, a microballoon storage is also estimated. For each form it is necessary to develop (1) installed capital cost, (2) filling and emptying equipment costs, and (3) parasitic energy consumption costs.

For storage of pressurized gas, a variety of conventional pressure vessel forms are available. These can be characterized by operating pressure; low (<500 psi), moderate (to 2000), high (2000-5000) and very high (5000-10000 psi) pressure. Those considered are, standardized API spherical and spheroidal vessels (low pressure), steel pipes (moderate pressure), and steel pressure vessels (high to very high pressures). Commercial estimates were used where possible. The question of an optimum pressure is considered; in fact the capital cost minimum is very broad (due to the constant amount of material required to hold a given amount of gas independent of pressure). At high pressure, hydrogen embrittlement phenomena dictate rapidly increasing thicknesses with increasing pressures, to ensure safety. At some pressure (probably 3000-5000 psi) a change over to costly materials is necessary due to embrittlement phenomena. Only the possible necessity of high pressure availability (greater than 5000 psi) could make these options attractive. Economically, low and moderate pressure storage look most attractive with installed costs below $1500/million BTU.

Nonconventional pressure vessel technologies include (1) prestressed cast iron (PCIV) with integral liner, (2) prestressed concrete, (PCCV), (3) filament wound metal bladder, and (4) underground using overburden pressure to lessen structural requirements from the gas containing bladder. The PCIV vessel is not as economical as some of the conventional vessels, but appears to approach competitive costs in large sizes. Its inherent safety is attractive. The PCCV vessel appears to have a pressure optimum and scales well to large sizes. It has a low pressure cost minimum which appears competitive with conventional vessels; its safety may be a question mark. Fiberglass wound metal bladders were uncompetitive; replacing an inexpensive material with one more expensive (per unit load carrying ability could not be otherwise. Burial of pressure vessels is also uneconomical, due to the costs of underground construction; great depths are required for significant structural contributions from the overburden. Optimistic costs have been developed by some authors for drilling in bedrock, etc. but these are site-specific.

The installed capital costs of cryogenic hydrogen storage are developed, and seen to be attractive (<$75/MBTU) for large scale storage; at small sizes the cost in $/MBTU is near that for gas storage, about $1400/MBTU. Hydride storage capital costs approach $3400/MBTU, because of the high price of hydri and the volume, plus the necessity of a pressure vessel. Microballoon storag has the lowest vessel capital cost, current estimates being in the $18-32/MBT range. This microballoon vessel cost is deceptively small however, as a facility must be built to fill the spheres. This cost is included later in the overall system costs. The filled microballoons must be stored somewhere, albeit at ambient temperature and pressure and it is this small cost that is shown.

Single cycle parasitic energy costs are determined: pressurization costs, liquefaction costs, combined heat and pressure for the microballoon system all were developed and applied to the appropriate system. Cycling requirements (daily, weekly and seasonal) were added to the above costing data. Using two scales, the 34 MBTU and optimum size, the total cost (instal capital plus parasitic energy (present valued) plus cycling requirements) was calculated using electric rates as a parameter.

For either the 34 MBTU or the optimum scale, energy intensive systems such as liquefaction or microballoons, fared poorly for daily cycling. Low pressure storage was the most economical technique, with costs ranging from 1200 $/MBTU (present value) depending upon energy costs. For weekly cycling, a complex mix developed dependent upon energy costs. For seasonal cycling, the energy intensive, low capital cost systems, were superior in large sizes; for small (34 MBTU) quantities microballoon storage appeared to be superior (less than $100/MBTU) with low pressure and liquefaction storage costing $1100-1500/MBTU. The costs obtained are estimates, and indicated clear choices for large seasonal, and both large and small daily cycling. Several choices are viable for the other duty cycles. While microballoon storag estimates are rough, this technology does look promising.

STUDY OF THE BEHAVIOR OF GAS DISTRIBUTION EQUIPMENT IN HYDROGEN SERVICE

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EXTENDED ABSTRACT

INTRODUCTION

This program is part of a multi-year effort to supply needed information about hydrogen delivery in natural gas distribution equipment. The near-term objectives are to identify operating, safety, and material problems associated with the use of hydrogen in conventional distribution systems. As a first step, this program experimentally evaluated the behavior of representative gas distribution components in (pure) hydrogen service and generally addressed the considerations involved in the use of existing natural gas distribution systems for hydrogen delivery.

We constructed three model test loops, with gas distribution equipment donated by 16 manufacturers and utility companies. Two of the test loops, the Residential/Commercial Test Loop (RCL) and the Industrial Test Loop (IL) were designed to operate continuously. The third test loop, the Special Test Loop (SL), was designed for intermittent operation.

TEST APPARATUS AND PROCEDURE

All construction for the test loops was done in accordance with the utilities' Construction and Material Specifications and the ASME Guide for Gas Transmission and Distribution Piping Systems — 1976. The RCL consists of four subloops and a bypass. The pipeline construction materials are a) steel, b) copper, c) plastic (high-molecular-weight, high-density polyethylene), and d) cast iron. This model was designed to include components normally installed in typical residential and/or commercial service. The IL consists of one loop and a primary bypass. All pipeline material is steel, and the loop was designed to include components normally installed in typical industrial service.

In operation, compressors delivered either natural gas or hydrogen to the loops at constant pressure and flow (11 SCF/min to the RCL and 15 SCF/min to the IL). The compressed gases passed through an aftercooler to reduce gas temperature to ambient and then through a surge tank to dampen pulsations. A line regulator installation reduces pressure to 50 to 60 psig, simulating pressures in a steel or plastic distribution main. Other regulators downstream reduce pressures for low-pressure components, such as the cast-iron main of the RCL and all meters. RCL meters and the cast-iron section of the RCL operated at about 6-inches water column and IL meters at 8 psig. After being metered, the gases were piped to the inlet of the compressors, recompressed, and recycled. Flow was controlled and proportioned with regulators, valves, and bypasses.

The SL consists of one loop with a leak zone and bypass. The leak zone, a changeable section of pipe connected to the loop by flange joints, provides a space for testing and defining problems associated with leaks or leak clamps. In operation, a compressor circulates gas from 15 to 22 SCF/min at pressures from 50 to 60 psig. Flow through the leak zone was proportioned with valves and a bypass.

After satisfactory shakedown tests with nitrogen, the RCL and IL were operated for 2 to 4 weeks to gain baseline data on flow, temperature, and leakage characteristics of natural gas. The two loops were then switched to hydrogen operation and operated for an additional period of 6 months. The SL was used to determine effects of expansion through components and leaks.

OBSERVATIONS AND RESULTS

Gas Leakage — Three basic types of leaks can occur from a distribution system: permeation leaks, diffusion leaks, and orifice leaks. For identical pressure and temperature conditions, volumetric hydrogen diffusion and orifice leakage would range from about 2.5 times (laminar flow orifice leakage) that for pure methane to about 3.2 times (diffusion leakage) that for high-molecular-weight (e.g., 21) natural gas. Permeation leakage is a function of both the properties of the permeated material and the gas. Hydrogen has been measured to permeate through polyethylene pipe at a rate five times greater than methane.

Experimental measurements of volumetric leakage from the test loops indicated a hydrogen-to-methane leak ratio of 3.35 for the RCL and a hydrogen-to-natural gas (0.57 specific gravity) ratio of 3.0 for the IL. On an energy basis based on the high heating values of the gases, the ratios become 1.04 for the RCL and 1.0 for the IL. The magnitude of the leakage was small, less than 0.02% of main loop flows, for both loops and independent of the gas.

Gas Flow and Energy Delivery — The high heating value of hydrogen is 325 Btu/SCF, whereas natural gas heating values are commonly in the range of 950 to 1100 Btu/SCF. Thus the flow of hydrogen must be greater by a factor of from 2.9 to 3.4 to deliver energy at a rate equivalent to that of natural gas. Through use of empirical flow equations, a previous IGT study considered laminar, partially turbulent, and turbulent flow of hydrogen and natural gas in pipes. The study concluded that when compared at laminar flow conditions and identical pressure drops across a given length of pipe, the delivered energy for hydrogen would be only about 40% of that of natural gas. When compared at partially turbulent and fully turbulent conditions, the delivered energy would be from 80% to 90% of that for natural gas.

Experimental measurements of main loop flows indicated that the delivered energy for hydrogen was about 97% of that for methane in the RCL and about 80% of that for natural gas in the IL for equivalent operating conditions. This observation tends to substantiate the predicted turbulent flow characteristics. The laminar flow case has not been experimentally investigated.

Component Performance — There was no discernable difference in performance of regulators or valves (internal leakage was not evaluated) between natural gas and hydrogen operations of the model loops. Furthermore, there was no discernable change in the performance characteristics of any component during the 6 months of hydrogen operations.

A comparative statistical analysis of meter measurements from the IL indicated that there may be a small change in metering accuracy of hydrogen compared to natural gas. However, this analysis was by no means conclusive. Measurement accuracy comparison on an absolute basis is needed before this suspected difference can be determined significant. A more significant issue involving in-place meters is their capability to operate with the required higher hydrogen flows. Some (installed) meters would be undersized for hydrogen service where three times as much volumetric flow would have to be accommodated.

Analysis of Selected Components After 6 Months of Hydrogen Exposure — Selected components from the RCL and IL were analyzed both macroscopically (compared to duplicate components) and microscopically to determine any effects on materials of construction due to hydrogen exposure. The materials evaluation indicated that the metallic components were basically unaffected by the hydrogen exposure, but there are some indications that plastic products may have been affected by the exposure. Ring tensile tests of plastic pipes showed that the exposed sample elongated more than the unexposed samples; the length changes involved were of the order of 40% and 60% for the unexposed and exposed samples, respectively. It appears that definite changes took place in the properties of some greases and adhesives. Observations of pipe welds and cast alloys in manufactured components show porosity and other defects that would be considered marginal for hydrogen service (need for better quality control). Proof of this would require long-term exposure tests at operating conditions.

Safety Considerations — A safety-related issue that has been mentioned with the use of hydrogen is the tendency for hydrogen to undergo a temperature rise upon isenthalpic expansion. Although the Joule Thomson effects were observed through temperature measurements across regulating stations of the IL and RCL, the effect was small. The largest observed positive temperature change was less than 2°F for a pressure drop of 170 to 60 psig. Joule Thomson heating effects were not observed in tests with the SL for leaks to the atmosphere from a pipe. The process of hydrogen expansion through a hole in a distribution pipe was observed to be dominated by an adiabatic expansion and cooling of the gas stream similar to that through a nozzle.

HYDROGEN IN THIN FILM HYDRIDING ALLOYS[a]

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EXTENDED ABSTRACT

INTRODUCTION

Many metal alloys form hydrides at relatively low pressures at room temperature, some with hydrogen densities greater than that of liquid hydrogen. These capabilities have made them important considerations for hydrogen storage [1]. The surface reactions occurring during hydriding in these alloys are not well understood although surface characteristics are clearly important [2,3]. Thin films provide large well defined surfaces with which to study the gas-metal interface reactions. Films less than 1 micron thick have been shown to hold together during hydriding [4,5]. The decrepitation which generally accompanies the hydriding of bulk alloys, reducing them to powders, is avoided by using thin films. Furthermore, thin films may show other property differences from the bulk, specifically in the pressure composition characteristics and kinetics [6].

EXPERIMENTAL

$SmCo_5$ and $LaNi_5$ films were RF sputter deposited onto amorphous glass substrates from bulk alloy targets. The targets had been previously equilibrated for about 30 hours to ensure stability of composition and proper stoichiometry of the films [7]. $SmCo_5$ films were initially activated by heating to 200°C in 30 to 50 atm of gaseous hydrogen and then pressure cycling. The $LaNi_5$ films were activated using pressure cycling only.

This activation was carried out in the specific measuring apparatus. Three parameters were measured as a function of hydrogen pressure: magnetization, sheet resistance and film stress. A newly developed high-pressure hydrogen torque magnetometer was used to measure the pressure-magnetization characteristics as well as the hydriding kinetics of the $SmCo_5$ films [6,8]. Sheet resistance vs. pressure curves were measured for $LaNi_5$ films in a recently constructed high-pressure four-point probe resistivity cell [7]. The film stresses as a function of hydrogen pressure were made using a new flexure technique [5]. This technique employs the differential stresses developed in a bi-material strip (hydride film-glass substrate) which cause a measurable deflection of the strip to monitor the film stresses accompanying hydrogen absorption in the film.

RESULTS AND DISCUSSIONS

It has been hypothesized that stresses caused by film adhesion to the substrate affect the hydriding rates as well as the pressure composition characteristics [5,6]. Figures 1-3 show typical magnitization vs. pressure, sheet resistance vs. pressure and stresses vs. pressure. All three measurements show a gradual change above the expected plateau pressures of their bulk counterparts, and not a sharp change as one would expect accompanying the plateau transformation between hydride phases. This indicates that the phase transformation from the α- to β-hydride phase is inhibited. The major inhibiting force is probably the substrate induced stresses which inhibit the normal expansion accompanying hydriding. Thinner films deviate more strongly from the bulk behavior as would be expected. For sufficiently thin films it appears that the α-β phase change is entirely inhibited and the hydrogen composition limited to that of the solid solution. One would further expect that the hydriding rates would be slowed by the inhibiting stresses. This has been shown to be the case for $SmCo_5$ [6]. These results indicate a pressure composition curve like that in Figure 4 for thin film hydrides rather than the flat plateau seen in bulk specimens.

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[a]Work supported by the U.S. Department of Energy under Contract E-(40-1)-5246.

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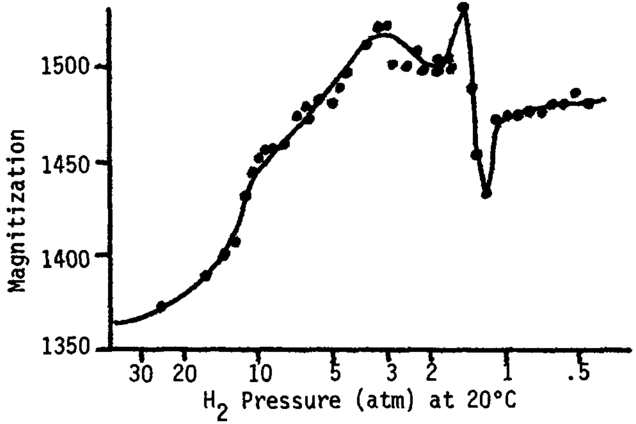

Fig. 1. Magnetization vs. Pressure for a 1500Å $SmCo_5$ Film.

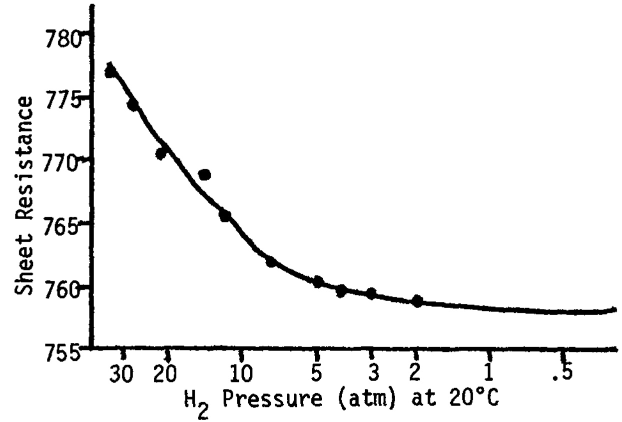

Fig. 2. Sheet Resistance vs. Pressure for 1500Å $LaNi_5$ Film.

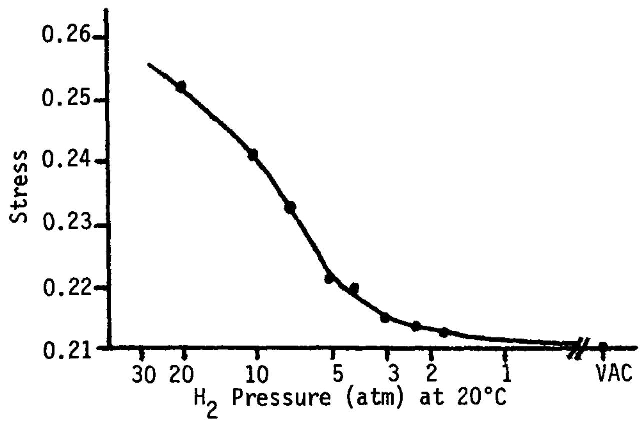

Fig. 3. Stress vs[illegible]ressure for a 1500Å $LaNi_5$ Fil[illegible]

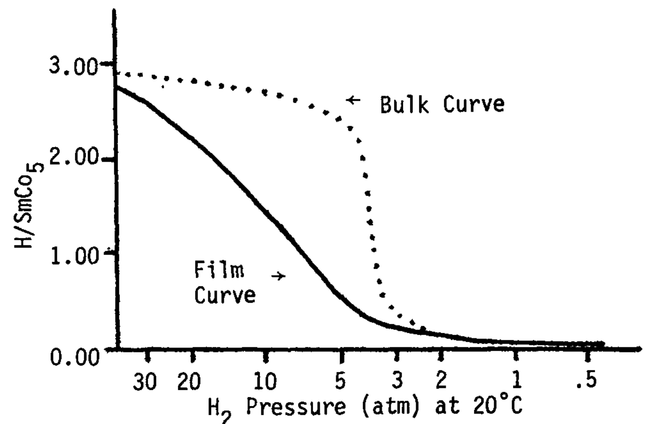

Fig. 4. Pressure Composit[illegible] Curve for a 1500Å $SmCo_5$ Film.

SESSION 3F

ECONOMICS AND POLICY III

A METHOD FOR ESTIMATING ESCALATION AND INTEREST DURING CONSTRUCTION (EDC AND IDC)

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EXTENDED ABSTRACT

Physical facilities require time to be constructed and put into operation. The construction and preoperation period (called "construction period" for convenience) can range from a few months for a residential dwelling to as long as ten years for a major energy facility. During this time, various events take place, such as raising funds, purchasing equipment, construction by the labor force, preoperational testing. Money is paid out for labor and material throughout. When there is an inherent inflation in the economy, more money is needed if the acquisition of goods and services are delayed. On the other hand, the paid out money represents an investment for which an interest must be accumulated. From the project viewpoint, it is important to know how much capital has been invested altogether by the time the facility is ready to perform its intended duty. Furthermore, it is also important to know what fractions of this capital are due to goods and services, escalation, and interest during construction. This knowledge is a prerequisite for raising capital, for setting rates, and, in general, for assessing the economic character of the facility under consideration.

This paper presents a simple methodology for relating the capitalized cost of a project at commercial operation, $I(t_{co})$, to factors such as discount rate, escalation rate, and construction period. The dollar is qualified with a date at which time it is used. Thus, $I(t_{co})$, measured in dollars at the time of commercial operation, is defined as $I(t_b)$, the estimated capital cost at the base time t_b, multiplied by the factor $f = 1 + f_{EDC} + f_{IDC}$, where f_{EDC} and f_{IDC} are respectively the fraction of escalation and interest during construction.

Seven payout schedules of the cash flow are considered in the calculations of f_{EDC} and f_{IDC}. They are

1. "One-shot" payout
2. Level payout
3. Linearly decreasing payout
4. Linearly increasing payout
5. Symmetric S-shaped cash flow
6. S-shaped cash flow — Left-side skewed
7. S-shaped cash flow — Right-side skewed.

For the first five payout schedules, closed-form formulas for f_{EDC} and f_{IDC} are obtained, thus facilitating the computation tremendously. The last two schedules yield rather complicated formulas for f_{EDC} and f_{IDC}. Numerical tables are provided for two common cases: (a) 50 percent of the cash flow takes place at 40 percent of the construction time, and (b) 50 percent of the cash flow takes place at 60 percent of the construction time.

For each case, an escalation rate, y, (percent per year) for goods and services is assumed. The discount rate, x, is the effective after-tax cost of money to the owner of the project. The construction period, B, is treated as a parameter.

The formulation is invariant under constant-dollars and inflationary modes of calculation. When the constant-dollars mode is used, both x and y are relatively small (e.g., 6 percent per year for x and 2 percent per year for y). When the inflationary mode is used, both x and y are relatively high (e.g., 10 percent per year for x and 6 percent per year for y).

Escalation and interest during construction are strong functions of inflation and construction period. An optimum construction strategy is the one that minimizes $I(t_{CO})$ when the date of commercial operation is known. Factors involved in this minimization process include general inflation rate of the economy, specific escalation rate of the commodities, interest rate on funds used during construction, and construction period. The formulation as provided in this paper allows the selection of an optimum construction strategy.

A numerical example is also provided.

THE CONTRIBUTIONS TO THE ENERGY SUPPLY OF THE INDUSTRIALIZED COUNTRIES FROM NUCLEAR ENERGY SOURCES AND REGENERATIVE ENERGY FLOWS

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ABSTRACT

There are 5 problem areas associated with the energy economy of the industrialized countries

- continuing increases in energy consumption
- decreasing fossil fuel reserves
- increasing amount of harmful byproducts produced through burning fossil fuels
- rising energy price level
- lack of general public acceptance of large scale technologies

In order to resolve the first four of these problems the industrialized countries have, in recent years concentrated their efforts on developing nuclear energy supply technologies, but due to the lack of public support, have also turned their attention to regenerative energy sources. The aim of this paper is to investigate the transition from the widespread use of fossil fuel energy sources to nuclear and regenerative energy sources.

The determination of potential areas for nuclear and regenerative energy production is based upon:

a) technical
b) ecological and
c) economic

criteria.

From the available nuclear energy supply technologies, the light water reactor and the high temperature reactor will be those considered for electricity and heat process production (coal gasification to produce H_2 and SNG).

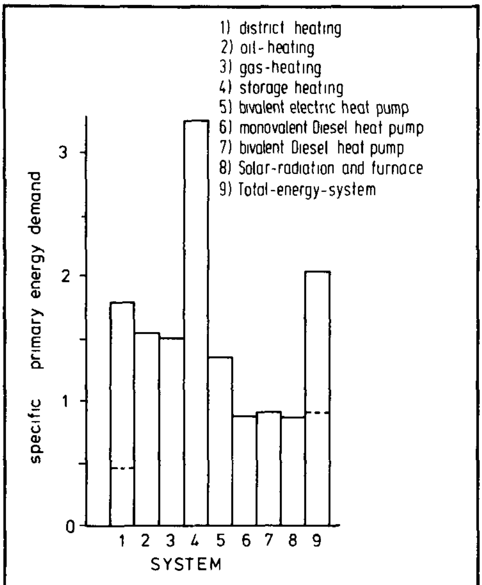
Of the regenerative energy supply technologies

- several heat pump systems
- solar installations
- geothermal power stations
- wind energy installation, and
- total energy installation

will be analysed.

The result is a relation between energy, ecological and economical criteria (the examples are Figs. 1, 2 and 3).

The last chapter of this paper analyses the supply potentials of the nuclear energy systems and the regenerative energy flow systems.



KFA	Relation between specific primary energy demand and the use energy demand of various heating-system	STE

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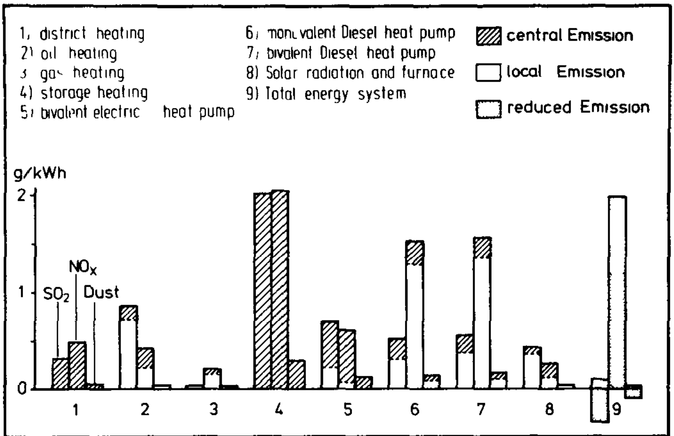
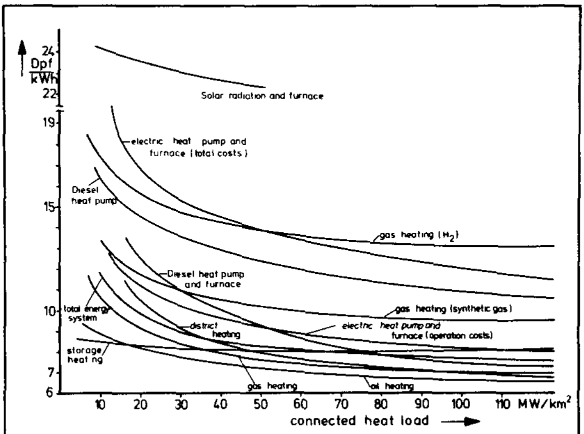


KFA | Specific Emission of various heat-systems | STE



KFA | Total costs of heating-systems | STE

DO

FUTURE TASKS FOR NUCLEAR ENERGY

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EXTENDED ABSTRACT

These remarks address the likely future role of both fission and fusion technologies in the context of their application to society's total energy needs, which are substantially more extensive than the demand for electric production alone would indicate.

A particularly important task will be that of energizing the synthesis of chemical fuels to replace the natural ones that, b y their high energy density, now so conveniently power our transport systems. Likewise, in an energy dificient era, we may well have to curtail the squandering of the highest thermodynamic grade of energy, represented by electricity, on duties demending only low temperature heat, even though it costs us convenience.

Such wide use of nuclear energy, however, could merely transfer the nature of a still necessary primary fuel source, so such plans must b e still accompanied by measures either to husband the supply of the substituted nuclear fuel material or hopefully to exploit some virtually unlimited resource of nuclear energy.

Until fusion is fully proven, we must perforce concentrate on conserving our natural supply of fissile material, and present estimates of this indeed warm of need to improve considerably on present profligate use in uranium light water moderated reactors, operated without reprocessing. Use of more efficient, recycled "advanced converters" could only sustain on our known uranium resources a few decades longer. In the long haul, further net production of fissile material is also required and, as yet, the only proven approach is by way of the fast breeder. This, however, does not mean that all fission reactors would eventually have to be fast breeders. Indeed this could be considered a far from universally desirable escape, if only on the grounds of perceived additions to an already protracted licensing procedure and present projections of capital cost.

Fortunately, the occurrence of another fertile material, namely thorium, offers a more practically established solution, for the high neutron yield of the U-233 which can be bred from it can very substantially reduce the fissile make-up requirements of the necessary thermal reactor "work horses". A very important attribute of this arrangement is that the nature and functioning of the thermal reactor power plants are not affected by where or how the fissile feed originated. This greatly facilitates a smooth transition from the use of FBR blankets as origin of the fissile feed to later use of either fusion or particle beam-driven alternate sources of fissile material, if and when such seem to offer real advantage.

The prospect of such an orderly transference is a particularly attractive one in view of the certainty of a widely distributed fission reactor existent by the time these technolgies are ready for commercial use.

There are, in fact, other reasons of an altogether different nature which also favor the use of thorium. These relate to the practicality of high temperature heat production, which may become an important factor in ecnomic chemical fuel syntheses. The key point here is that high temperatures from reactors, at least thus far, are seen as demanding use of a homogeneous graphite type of core, which construction operates much more effectively on the thorium cycle.

The thorium cycle is thus seen as providing much more than a use for an additional raw material, but rather as a vital link in the coordinated use of nuclear energy.

POLICIES AND STRATEGIES TO ACCEPT SHIFTS IN TRANSPORTATION MODES

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EXTENDED ABSTRACT

INTRODUCTION

Energy availability and costs may cause or accelerate major shifts in transportation means from individual/personal modes (automobile, truck) to mass/group nodes (bus, rail). To prepare for this possible shift, major policy and planning strategies will need to be made to accommodate this shift in a meaningful manner as it will impact on national, regional, urban development and growth patterns. This paper will concentrate on exploring the possible consequences of this phenomena at the urban scale and will define possible strategies and policies that might be implemented.

EXISTING MORPHOLOGY

Presently our reliance on the individual automobile has allowed development to leapfrog areas of high land values to areas of low land cost. This kind of free movement has caused our urban morphology to become continuously extended. Cities in America that experiences major growth after WWII usually display two kinds of urban form (organization): a CBD urban core and an extended field of places connected by channels of movement. These channels have been consequently developed with commercial development in most cases.

Zoning, which in this country primarily separates functions, has reinforced this extended development because it initially was a reaction against density. In the 1960's visionary architects and urban designers were starting to understand the anti-holistic nature of this situation and were forecasting a technological rebirth of holism in the guise of megastructures. In many cases these so-called cures were worse than the illness. The primary problem with these solutions was not their concepts of integration, but the manifestation of these ideas into Orwellian robot cities. An important aspect of these approaches was their reliance on an energy intensive technological approach that is clearly not feasible with our present technology. Another factor that was also a negative feature of these curealls was their penchant for starting anew, and disregard for the existing urban fabric. Clearly any attempts at policy-making for urban revitalization must not only be holistic but it must deal with already existing morphology.

The major determinant that will affect our urban environment however, will be its movement systems. Historically and in the present, movement, whether vertical (the impact of elevators changed the scale and density of urban form at the turn of the century), or horizontal, defines the organization of the built form of the environment.

SYSTEM CHARACTERISTICS

The development potentials characteristic of an urban fabric dependent on mass transit is one which is nodal in its form. Mass transit such as buses, trains, etc. cannot function efficiently and economically if the user can embark or disembark at whim. There must be defined stops at defined distances apart from each other. These stops -- if the system is utilized -- cause land values to increase in their proximity and thus create a hierarchy of urban form spreading out from the stop at distances usually related to walking distance. The dependence on mass transit also usually maximizes pedestrian patterns while the auto-based system usually negates the need to walk.

A logical assumption is that any increased dependence on, or development of mass transit would have as one strategy to connect existing points of our urban network to each other. Some of these existing nodes might be malls, historic areas, pre WWII CBD, educational centers, etc. The value of these places would most likely increase due to their new position on the mass transit system.

STRATEGIES AND POLICIES

The following is a listing of possible strategies and policies that if implemented would reinforce in a significant way mass transit stops.

<u>Vertical Zoning</u> The structuring of functional components in the vertical dimension. This is a traditional means of ordering urban environments. This mixed-use approach allows for a more efficient use of the built environment.

<u>Pedestrian Areas</u> Develop pedestrian-only areas and enhance the pedestrian environment by creating amenities such as covered walkways, better lighting and reduced pedestrian/auto

conflicts. This does not mean completely eliminating the automobile from these environments, but it does mean putting the pedestrian ahead of the auto in priorities.

Special Zoning Districts These districts would enhance the existing functions and characteristics by providing incentives for complimentary uses.

Increase Densities Mass transit systems need density patterns that are more condensed than the auto. This might be encouraged by allowing much denser zoning patterns than that presently operating in most U. S. cities. These denser patterns should be located within suitable walking distances from transit stops.

Tax Incentives/Development Incentives Provide incentives to make it economically more attractive to re-use existing fabric and to locate in already established areas to try to offset higher initial costs due to land values. Reverse incentives could be placed on development in virgin areas that are not integrated with mass transit systems.

Power Density Distribution Density should take into account power distribution to reduce energy distribution losses.

Bicycle Amenities Provide amenities to reinforce alternative soft modes such as bicycles, by providing bike paths, lockups, shelters, and pedestrian paths which converge on transit system stops. This is a successful European tradition.

These strategies work on two levels; on one level they reinforce a shift to mass transit by encouraging the development of population distribution that historically and functionally is needed to make mass transit economical and feasible. On another level they are aimed at creating a more attractive and amenable environment for the user.

ALTERNATIVE CHOICE OF ENERGY TECHNOLOGY: A COMPARATIVE ANALYSIS OF BRAZIL AND INDONESIA

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EXTENDED ABSTRACT

A comparative analysis of the energy strategy alternatives available for the cases of Brazil and Indonesia is performed based on their own natural resources characteristics and economic capability. The energy profile of both countries will be traced by drawing the present pattern of energy demand and its future development as against the available domestic energy resources.

The alternative energy technologies accessible to both countries will be discussed in a comparative framework. Some indigenous technological enterprises will be presented together with their effects as opposed to importation of technology. The issue of importation of high technology to increase the efficiency of energy generation and utilization will be comparared with the creation of a high degree of dependence on foreign supplies; domestic technology would enhance higher independence at the cost of lowered efficiency. Based on factual information, we will explore some aspects of the relationship between energy technology and economic growth. The nature of the relationship between economic growth and the choice of energy strategy will be analyzed by using a long-run macro-economic growth model as a framework for analysis. There will be no computational results presented by using this model. This is partly due to the inadequate energy series. The paper, however, presents preliminary findings of the comparative study.

Brazil and Indonesia present a very interesting bipolar system of energy and economic endowments. Indonesia is the eighth largest exporter of oil globally and belongs to OPEC, while Brazil is the sixth largest importer. Both countries have approximately the same population (140 and 115 millions, respectively), but each has a clearly distinct culture and

religion (Oriental traditional, Moslem and Western, modern Catholic, respectively); both have large potential for solar energy, biomass and hydro energy; Brazil has large deposits of shale oil, while Indonesia has a large geothermal potential; Brazil has an ambitious nuclear program ongoing while Indonesia is planning for one; Brazil is in the upper bracket of economic development among Third World nations, while Indonesia is in the lower income bracket. This analytical comparison will provide an important policy lesson of the choice of energy technology for the respective countries. More importantly, it will also provide generalizations about energy policies for developing countries.

The crucial questions are then whether the choice of energy technology has an important bearing on the future development of these countries, and on what basis technology choices will be made. The comparative analysis is conducted within the institutional setting appropriate to the respective countries.

HYDROPOWER, COAL AND COAL GASIFICATION AS AN ALTERNATIVE ENERGY SOURCE FOR GREECE

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EXTENDED ABSTRACT

A National Energy Plan and Planning Policy is probably one of the most urgent technical, economical and political (in a broad sense) problems of Greece today.

Three factors of cardinal importance compose the basis of the energy problem. First, the dependence of the Country on imported oil to cover almost 70% of the total national energy needs. This percentage will probably increase within the next decade of anticipated rapid economic growth and industrial expansion. Second, the hard currency for the imported oil bill was exceeding $1.3 billion for 1978 and may reach $6 - $7 billion by 1989 - the equivalent of the total present exports of the Country. Thus, the energy payment alone may easily deplete the currency reserves, leaving little for equipment, machinery and other imports required by the production and development sectors of the economy. Third, the energy planning (and economic-social development) is a key prerequisite of the Country's entrance (and success) in the European Common Market.

The energy dependence (and currency-financial burden) can be greatly alleviated and cut almost by half, through a systematic rational energy planning and development of domestic energy sources. These are:

(a) Coal and tyrphi (peat) production and coal gasification along with oil-gas exploration and production in the Thassos-Kavala region in Northern Greece.

(b) Hydropower development and new hydropower plant expansion and dam building, based on a new more rigorous rational planning approach, in a period of global energy crisis. Dam and hydropower stations building shall include smaller installed capacity plants - up to 4-10 MW. Today hydropower uses are about 12-14% of the technically available (and economically sound) hydropower potential of the County. The hydropower planning proposed, may increase within a decade five times the present level of hydropower use, i.e., up to 70-80%. Available water from such dam construction will be of great significance for: (i) irrigation; (ii) water supply; (iii) flood control and reforestation; (iv) environmental quality-protection; (v) ecological stability and diversity of the country's ecosystems.

(c) Energy conservation planning and implementation along with solar and other domestic energy source applications (wind, geothermal).

It should be emphasized that the latter sources of energy, hydropower, solar, wind and geothermal, are non-polluting and renewable. In the long run they become more economical and more beneficial for the econom and welfare of the Nation than the polluting, non-renewable and non-available energy sources such as nuclear and fossil fuel.

ELB

STATE LEVEL RENEWABLE ENERGY RESOURCE ASSESSMENTS

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EXTENDED ABSTRACT

The rather inoccuous title of this paper belies the underlying nature of the social change which engendered it. Renewable energy resources assessments are the result of a fundamental change in attitude toward many of our most basic institutions. Those institutions include utilities, the federal government, the state government, and energy supply companies. The emerging trend toward alternative energy use is essentially a trend towards decentralization and self-reliance. The switch to alternative, and especially renewable alternative energy resources requires a decentralized approach. To undertake renewable energy assessments the state level is one methodology under consideration. Consequently this level of analysis was undertaken in the State of Alaska in order to determine what potential there is for basing the economy of this state on renewable, alternative sources of energy.

There is a strong realization within Alaska that it, as well as the rest of the world, is at a turning point, and will need to prepare for a transitional period to greater dependence on renewable energy sources. In order to prepare for this a well-documented, ongoing, renewable energy resource assessment is required.

The research plan for this assessment was as follows:

I. Determine all presently known information about renewable energy resources in Alaska.
II. Assess and classify those resources by the following parameters.

A. Type of resource (solar, wind, wood, geothermal, etc.)

B. Assess the resources for the range of thermal application:

(1) Less than 100°C
(2) 100 to 315°C
(3) 315 to 600°C
(4) Greater than 600°C

This assessment determines for which end use the resources can be useful.

C. Assess the resources as to the substitution possibilities, utility, storage, and portability.

D. An attempt was made to estimate the supply and demand balance of the State of Alaska for the year 1991 with the available data and information. Several assumptions were necessary in order to provide a background for questions in assessing the renewable energy resources. The assessment assumed that a mandate, both politically and socially, existed within the political structure of the State to develop renewable resources instead of continuing to use non-renewable resources.

Research was done in an experimental class for upper-division undergraduate students. The object of this class was to introduce the tools of energy analys into the core corriculum for natural science majors. Students and the author formulated the previously outlined research plan and students did the first phase of research. The result is a first overview of the supply/demand balance of energy sources by end use, and potential substitution for the year 1991, assuming a 3.5% annual increase in energy use in all sectors. With a forgiving eye toward the economic factors of the study, here are some estimates of a renewable resource economic basic for a minor incentive case: 10% investment tax credit, and present solar tax incentives:

TABLE 1
ENERGY USE ANALYSIS FOR SUBSTITION BY RENEWABLES

	Percent 1977	Gross *Energy(KJ) 1977	Gross Energy(KJ) 1991
I. PETROLEUM LIQUIDS	66.5%		
A. Power Generation(Electric and steam)	(9%)	1.25×10^{13}	1.95×10^{13}
B. Heating	(16%)	2.27×10^{13}	3.55×10^{13}
C. Transportation	(75%)	1.00×10^{14}	1.56×10^{14}
		1.35×10^{14}KJ	2.11×10^{14}KJ
II. NATURAL GAS+	26%		
A. Residential	(37%)	1.92×10^{13}KJ	3.00×10^{13}KJ
B. Power Generation	(63%)	3.32×10^{13}KJ	5.19×10^{13}KJ
		5.24×10^{13}KJ	8.19×10^{13}KJ
III. COAL			
A. All use - figure based on Usibelli Production 700,000 tons(8400BTU/lb.)	6%	1.17×10^{13}KJ	1.84×10^{13}KJ
IV. HYDROELECTRIC	2%		
Electricity production (From State of Alaska estimates of capacity and 60% CF)		3.97×10^{12}KJ	6.21×10^{12}KJ
TOTAL STATE USAGE (Except industrial gas)		2.01×10^{14}KJ	3.17×10^{14}KJ

*Conversion @ 135,000 BTU/GALLON or 145,800 KJ/GALLON

+Production for re-injection and ammonia-area not included.

RDS

TABLE 2
POTENTIAL CONTRIBUTION OF RENEWABLE SOURCES OF ENERGY FOR ALASKA

Resources	1977 Contribution x 10^{13}KJ	1991 Potential x 10^{13}KJ	End Uses	Processess	Comments
Hydroelectric	.397	.765 (.368 new generation)	Electricity	Dam & Reservoir	High Capital demand is major obstacle
			Minimal *Transport(?)*		Three dams *presently* planned. 11 most feasible sites
Wind	negligible	1.05	Electricity	Mechanical W.E.C S	Coastal villages *are main develop-*ment area.
					50% of rural electrical needs by 1991
Geothermal Hot Springs	.01	.0222 50% total utilization	Space heating, recreation, greenhouse	Direct Heat Exchange	Hot springs sources
Magna Sources	0	(ultimate potential 5000)	Industrial Heat Electricity		Magmatic sources very difficult Technical problems impede application and development
Solar Active Passive	negligible	1.03	Space heating,* Hot water	Collectors, passive design	25% of heating needs in the railbelt
Photovoltaic	negligible	.01	Electricity	Photovoltaic Devices	Some potential exists for rural applications
Wood/Biomass/ Agriculture (includes alcohol fuels)	(wood)* .41	.65	Space heating	Combustion	In 1977 about 10% of space ht. is estimated to be supplied from wood.
Alcohol		+ .21	Alcohol fuels 90/10 gasohol		254 million gallon of motor vehicle fuel required in 1990. Figure is 10% from alcohol.
Tidal Power	0	(ultimate potential 1150)	Electricity	Barrage & Hydroturbines	Potential is great, but capital require-ment also great.

*Based on 118 x 10^6KJ/capita space heating requirement.
+Based on 90000 BTU/gallon for Ethanol.

TOTAL (1991)
All Renewables with Development Feasibility: 3.73×10^{13}KJ

TOTAL STATE OF ALASKA REQUIREMENTS (1991)
(3.5% ann. growth): 3.17×10^{14}KJ

SHORTFALL 2.79×10^{14}KJ

As can be seen, the foreseeable development of renewable energy sources will only be able to supplant 12% of total state needs at our projected rates of development. The study shows where renewables can made a contribution and where they fall short (transportation energy). This study was an assessment however, and the actual contribution of renewable energy sources can be much more substantial. Qualifications on the development scenario, social and economic factors, and many other complicating factors point to the need for much more detailed, intensive analysis.

THE ROLE OF THE COMMUNITY COLLEGE IN ENERGY EDUCATION

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EXTENDED ABSTRACT

Education of the public will be a major factor in the implementation of any energy policy in the United States. This is the case for many reasons, but chief among them are: 1) the inherent complexity of the energy problem, 2) deep and growing mistrust and suspicion of government and industry motives by the average layperson, 3) the uniquely "community-specific" aspects of many energy related policy decisions and 4) natural resistance to acceptance of new lifestyles and technologies. A realization that these are important parts of the overall problem will immediately underscore the importance of the Community College in any coherent policy of public education. Indeed, many Community Colleges are already playing active, concerted and innovative roles in energy related educational programs, as is evidenced, for example, by the Energy Management Project of the League for Innovation in the Community College.

The purpose of this paper will be to set forth the educational steps that are being taken by Dutchess Community College in an effort to address the four areas outlined above. Naturally, the particular geographic location of Dutchess will be reflected in the specific nature of some of the problems it is emphasizing, but the overall multi-faceted educational approach is one that is peculiarly appropriate to the institutional framework of the Community College and can and should be pursued effectively by all of them.

Specifically, we will discuss the following substantive and pedagogical issues. 1) Day courses that focus on the social, political and economic aspects of the energy problem. 2) Day courses that concentrate on the technology of alternative energy sources. Included among such courses are those meant to train or upgrade the proficiency of servicemen and technicians in energy related technologies. 3) Day and evening (continuing education) courses that address such areas as conservation in the home, installation of solar panels, energy efficient home design, etc.. Such courses are often taught in close cooperation with local utilities and industries. 4) Courses that deal directly and specifically with problems of immediate or ongoing community concern. Examples of such problems in our area which have been or are being addressed in courses are power plant siting, pollution of local rivers, etc.. 5) In-service

courses for highschool teachers who are attempting to teach energy related subjects at that level. 6) Utilization of the Community College as a clearing house for energy related projects and information. Included in this area are telephone "hot line" services and local radio and newspaper spot reports. 7) "Forums For Diverse Peoples" , are forums and round table discussions that will bring experts from many fields into the community and give community members a chance to enter into discussions with them.

Along with the specific items mentioned above, it should be noted that the Community College philosophy of education also requires that we reach out to people that are unable to come to us and that we identify new audiences that can benefit from the kind of education we offer best. Consistent with this philosophy, we have an established program in the local state prison and are considering programs in old age and convalescent homes. In addition, our "Kids College" brings elementary school children into special classes at the College to introduce them to topics and equipment beyond the scope of their own schools, but within the capabilities of their minds.

In order to implement such a wide range of courses and special projects, the Community College must be particularly encouraging to its faculty in terms of allowing them to maintain proficiency in many areas. This is accomplished by continual in-house seminars as well as a policy of allowing faculty to attend conferences, symposia and "short courses". In addition, the Colleges encourages a close interaction between its faculty and local utilities, industries and community action groups. In this way it becomes relatively easy to solicit the aid of these groups in our own efforts and to keep up to date on their perceived needs.

In conclusion, it should be emphasized that the Community College is publicly funded, offers flexible hours, convenient locations and an extremely diverse and changing curriculum to meet community needs. All of these factors make it easy for the prospective student to accomodate a busy work schedule and family demands. Whereas four year colleges and universities supply the depth of education necessary to produce advanced degrees, we can provide the breadth of education necessary to build a broadly based public understanding of the energy problem and the programs instituted to help alleviate it.

ALTERNATIVE ENERGY FOR PUERTO RICO

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The Office of Energy of Puerto Rico has been allocated the sum of four million nine hundred fifty thousand dollars ($4,950,000) by the Puerto Rico Legislative Assembly for the purpose of the development of alternative sources of energy in Puerto Rico.

It is envisioned that the program will include projects in solar thermal, solar cooling, photovoltaics, ocean thermal energy conversion (OTEC), bioconversion, wind, hydro, energy conservation and energy storage areas.

Although primary responsibility for the administration of the program rests with the Energy Office, assistance will be sought from various internationally acclaimed scientists who will serve in an advisory capacity.

The paper presents details on the precise nature of the program, the timetable for predicted events and milestones, and on the potential for the contribution of alternative energy sources toward the solution of the Puerto Rico energy problem. Specific guidelines are included which encourage the participation of universities, research and development firms, and of government, in the accomplishment of the objectives, with a special emphasis on the development of a matching fund base for enhancement of the program.

THE EFFECTS OF OWNERSHIP OPTIONS, GOVERNMENT POLICIIES, AND OPERATIONAL ALTERNATIVES ON THE ECONOMIC VIABILITY OF INVESTMENT IN SMALL POWER SYSTEMS

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EXTENDED ABSTRACT

INTRODUCTION

The Alternative Power System Economic Analysis Model (APSEAM) is an interactive computer model which can be applied in three ways: (1) The model projects the annual, after-tax costs of capital investment in various conventional and non-conventional energy technologies for each year in the investment time horizon. In total, these costs are termed "lifecycle costs"; (2) The model serves as an investment analysis tool; and (3) The model serves as a tool to investigate the effects of policies on specific investors.

CASH FLOW MODEL

The basic model premise is that the evaluation of investment alternatives should be based upon a "lifecycle cost" perspective. This perspective is obtained through use of a cash flow methodology. In a cash flow model, detailed cash flow information is projected for each investment alternative for each and every year in the investment time horizon. Within APSEAM, this annual cash flow information is aggregated to produce various measures of the lifecycle costs of each of the investment alternatives. The model can be used to quantify the effects of variations in such factors as technology cost (capital costs and operations and maintenance costs), general economic conditions, investor-specific financial conditions, the method of financing of the capital investment, the resource (e.g., solar insolation levels), technology performance over time, supply and demand matching, incremental plant start-up, and component replacement scenarios.

INVESTMENT ANALYSIS TOOL

The Alternative Power System Economic Analysis Model also functions as an investment analysis tool. As such, it seeks to answer the question: "What is the relative worth of different investment alternatives to a specific investor?" This question is much broader than the question "What are the life cycle costs of different investment alternatives?" for it takes into account a specific investor's financial environment (for example, his ability to absorb those costs, his cost of capital, etc.) as well as the specific investment alternatives available to that investor.

The model aggregates the projected cash flow information to produce an investor-specific "investment profile" for each investment alternative —

a set of figures of merit which enable that investor to make an informed decision. The specific investor types which can be treated include private utilities, municipal utilities, corporations, and individuals. In addition, various types of joint ventures and leasing arrangements can be evaluated.

POLICY ANALYSIS TOOL

In addition to functioning as a lifecycle cost model and as an investment analysis tool, the model also functions as a policy analysis tool. As su[ch] it seeks to answer the question: "What is the impact of various governmental actions on the perception of specific investors concerning the relative worth of various investment alternatives?"

The model enables the impact of specific state and federal actions on the perception of specific private sector investors concerning the economic viability of the various investment alternatives to be quantified. For example, the model can quantify the implications of utilizing: various methods of depreciation accounting, various provisions for tax credits, various rules concerning the carry-back and carry-forward of tax credits, and/or operating losses.

MODEL VALUE: USE OF OUTPUTS

As an investment analysis tool, the model produces investor-application-specific projections of how specific investors are likely to perceive the worth of a particular investment alternative relative to others. This information, coupled with the market size potential which each of those specific investors represent, provides the basis for meaningful estimates of market penetration. Hence, model-derived information can serve as valuable input to macro-market penetration models. In like manner, as a policy analysis tool, the model specifies what the impact of specific policy decisions is on the perceptions of specific investors in specific applications concerning the relative worth of various investment alternatives. Aggregated, this information enables the effects of alternative governmental policies and incentive strategies on the market penetration potential of various energy technologies to be quantified. In this way, the costs and the expected benefits associated with alternative policy options can be related and optimal trade-offs identified, both from the standpoint of the government and of individual investors. The flow diagram shown in Figure 1 specifies the various categories of inputs to the model and how the model output can serve an essential function in understanding the role of various energy technologies in the energy marketplace of the future.

MODEL APPLICATION: TWO CASE STUDIES

The model has been used in a residential photovoltaic case study in order to: (1) determine the impact of homeowner income level, homeowner discount rate, system size and cost assumptions, policy decisions (such as the rate at which excess electricity generated by the homeowner can be sold back to the grid), available financing opportunities, the coincidence of load requirements and technology performance, and general economic conditions

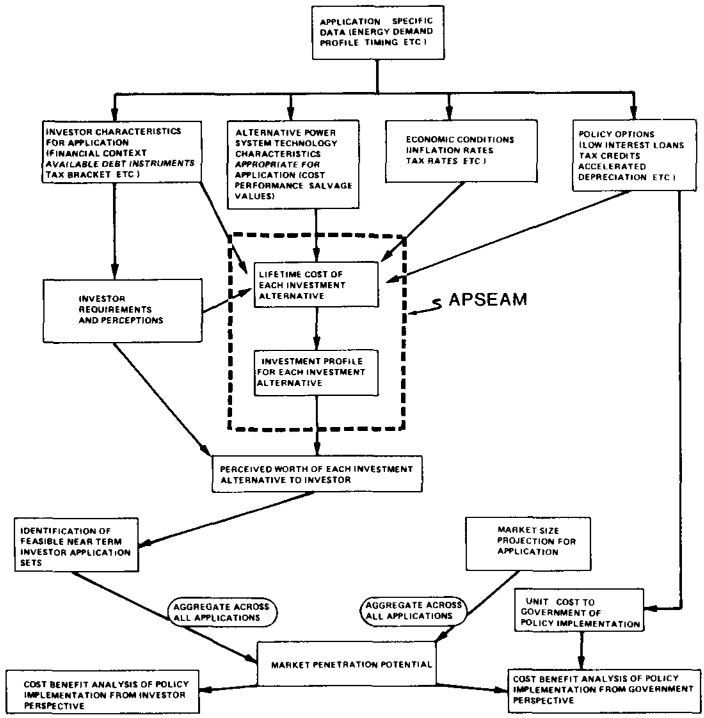

Figure 1. Information Flow Diagram and Model Context

on the direct cost of a PV system to a homeowner; (2) calculate the rate at which a business corporation or utility would have to lease PV systems in order to justify the capital investment in such systems; and (3) specify those situations in which specific ownership alternatives are preferred by specific investors (risks, aesthetic considerations, etc., aside) to others. The results for the base case show that homeowner purchase of a PV system is in general preferable to homeowner leasing of those systems from business corporations or utilities.

The model has also been used in a generic study of the worth of various power system technologies to an industrial investor seeking to satisfy both thermal and electrical power needs. The impact of factors such as the financial context of the investor, the manner in which the investment is financed, the timing of plant construction, start-up, component overhaul and replacement, and regulatory and legislative policies on the economics of various small power system technologies in the energy marketplace has been quantified.

WOOD ENERGY IN WEST VIRGINIA

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EXTENDED ABSTRACT

INTRODUCTION

Until the middle of the nineteenth century wood provided nearly all of the energy for warmth, cooking and as industry developed, process steam and motor drives. Gradually, however, wood was displaced by various forms of fossil fuels, until recent years when wood no longer contributed significantly as an energy source.

Today, however, we find ourselves in a changing situation. There is a growing sense of urgency in the United States to develop "new, renewable" sources of energy. Thus, wood has been rediscovered as an energy source, and certain areas of the country find that their dependence on foreign crude oil might be lessened considerably.

Until recently only forest product companies with large amounts of wood waste were using much wood for fuel. Now, uncertain oil and gas supplies and increased fuel bills have stimulated interest in wood fuel among non-forest product industries.

This paper presents the findings of a study into the feasibility of using wood in West Virginia as an energy resource.

WOOD RESOURCE BASE

West Virginia has over 15 million acres of total land area. Of this, 25% is non-forest land covered by industrial and urban development, roads and highways, and cropland or grazing areas. Commercial forest land covers 74% of the State and is defined as capable of producing 20 cubic feet of industrial timber per acre per year. The remaining 1% is either incapable of producing timber crops or withdrawn from commercial timber use.

Of West Virginia's 11.5 million acres of forest land 60% is oak-hickory. Less than 3 million acres are maple-beech-birch. The remainder is softwoods and lesser hardwood types. Productivity is about 40 cubic feet per acre per year right now and is predicted to rise to 70 cubic feet by 2005. This is still low, for almost half of West Virginia's forest land is capable of producing 85 cubic feet or more per acre per year.

West Virginia grows a lot more timber than is being removed for wood products. However, one in every four hardwoods and one in every eight softwoods is considered unmerchantable because of defects, poor form, or species. Using this excess timber for energy purposes would allow higher quality timber to be grown for wood products while bringing increased economic activity to the State in the form of a wood energy industry.

The maximum amount of wood for energy that West Virginia forests could provide every year on a renewable basis, assuming that demand for lumber and pulpwood continues to be met, is 34 million tons or nearly 300 trillion Btu's of energy. Allowing for the impact of landowners reluctant to harvest, inaccessible land, and acreage restricted by law, forecasts show that approximately half of this maximum amount could actually be harvested for energy on a renewable basis.

HARVESTING AND TRANSPORTING FUELWOOD

In order for wood to prove a viable energy resource for West Virginia, however, it must be harvested and transported to areas where it can be consumed. The harvesting process in West Virginia is complicated by the steepness of the terrain. Approximately 20% of the State can be harvested with mechanized feller/retrieval systems with harvesting costs for wood chips falling in the $7.00 per green ton range. However, the remaining 80% of the State must be negotiated with hillside equipment. Three systems suitable for harvesting hillside timber are: skidding, cable yarding, and helicopter systems. Within each system, the timber must be manually felled by chainsaw. Harvesting costs for wood chips from these operations range from $16 to $37 per green ton.

The wood chips must then be transported to the user by either barge, rail, or truck. Barge transport is the cheapest in terms of cost per ton-mile but is severely restricted in the points it can service. Rail and truck, on the other hand, are more costly per ton-mile but provide flexibility in routing. Total transportation costs depend on both carrier rates and the number of cargo transfers required. However, trucking is typically cheaper than rail in West Virginia for distances under 175 miles, after which the reverse is true.

USAGE OF WOOD ENERGY

In 1977, the industrial sector in West Virginia consumed 92 trillion Btu's of natural gas and 18 trillion Btu's of residual oil (No. 6). In addition, 894 million gallons of gasoline were consumed by cars and trucks on West Virginia highways. These are all areas where wood energy could provide some relief in State dependence on non-domestic petroleum. This could be accomplished through the following wood-to-energy conversion techniques:

Direct combustion or the burning of fuel in the presence of oxygen for use as a direct heat source. The forest products industry has used direct combustion for many years mainly in an effort to reduce their waste disposal problems. Many furnace designs currently fire wood directly to heat either steam or air.

Gasification or the thermal conversion of wood to a gas that can be burned like natural gas or oil. Wood chips make an excellent gasifier fuel. With the advent of total tree chipping and pelletization equipment, wood gasification holds promise for the industrial sector. This process can be used to retrofit steam boilers that are designed to burn only gas or oil.

Pyrolysis or the decomposition of organic material with heat in the absence of oxygen. The char, oil, and gas produced by pyrolysis of wood can be used as fuel or chemical feedstocks. Pyrolysis is not widely used in the industrial sector, but could have application wherever the disposal of organic waste and the need for fuel occur simultaneously.

Alcohol can be produced from wood via hydrolysis or fermentation. It is an old concept, but one that was not economical until petroleum feedstocks became short in supply and high in price. Ethanol, a form of alcohol, is of primary importance. Ethanol-gasoline mixtures can be used as transportation fuel with little engine modification. Projected prices for conversion by acid hydrolysis range from 30¢ to 78¢ per gallon when credit is assumed for by-products. These costs compare favorably with recent gasoline production costs of 40¢ per gallon.

BENEFITS OF USING WOOD ENERGY

As a result of wood utilization as an energy resource, the economy of West Virginia will definitely benefit. Money spent for wood energy will support jobs within the State beyond the traditional petroleum distribution networks. In addition, regional incomes in remote areas of the State where timber is abundant will share in the wealth of this renewable, stable energy resource.

SESSION 4A

HEAT STORAGE AND TRANSFER I

MODELLING OF A TWO-TANK SEASONAL STORAGE SYSTEM FOR SOLAR SPACE HEATING OF BUILDINGS*

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EXTENDED ABSTRACT

Seasonal storage solar-thermal systems, in which the relatively abundant summer insolation is converted to heat and stored for winter use, offer the possibility of substantially improved annual useful output per unit collector area. Several recent studies have examined alternative design, sizing and operating strategies for these systems, and have compared their cost-competitiveness vis-a-vis direct solar heating systems and conventional heating devices. [1]

Previous studies have concentrated on storage via sensible heat. Typically, the storage medium has been water, contained in a single large tank, with the water assumed, for computational simplicity, to be "fully-mixed" (isothermal). While the single-tank, "fully-mixed" configuration is a reasonable bench-mark for defining first-cut sizing and design requirements, it has a number of serious shortcomings that limit the overall system performance.

The principal disadvantage becomes readily apparent by considering system operation at the start of the winter heating season. During this period, the temperature of the storage medium is at its maximum yearly value, causing the collector fluid inlet temperature to be high and hence collection efficiency to be low. While the heating load will reduce storage temperature, the process is gradual because of the considerable thermal storage capacity contained in the single tank, resulting in a period of up to several months following the onset of load of relatively low collection efficiency.

Temperature stratification of the storage medium will tend to increase collection efficiencies during this period. For a single-tank system, however, the performance improvement of the stratified over "fully-mixed" case may only be slight. While in the stratified system the hot water from the top of the tank passing through the load heat-exchanger returns to the bottom of the tank at a lower temperature, the temperature drop is generally small for the air-to-water heat-exchangers used in space heating applications, thereby providing only a modest improvement in collection efficiency. [2]

A novel two-tank storage system will be discussed at the Conference consisting of a large "seasonal storage tank" for summer collection, and a "diurnal storage tank" for collection of solar energy during the winter heating season. This system yields substantially higher collection efficiencies, by as much as 10-15 percent, particularly during the winter

space heating season. A simple schematic of the system is shown in Figure 1, where for clarity the two tanks are shown as physically separate. In an actual system, it may be more economical to construct the smaller diurnal storage tank by partitioning off (either physically or thermally) part of the larger seasonal storage tank .

By extracting heat preferentially from the diurnal storage tank to meet load requirements, its temperature is kept well below the temperature of the seasonal storage tank over most of the winter heating season. This provides a lower temperature source for the collector inlet fluid, enhancing collection efficiency. To the extent that the heat extracted from the diurnal storage tank does not meet load, additional energy is obtained from the seasonal storage tank, and finally from the auxiliary furnace. As the temperature of the seasonal storage tank is drawn down over the course of the winter season, the performance benefit from the diurnal storage tank becomes less important.

An approach to simulation of the system has been developed, and will be described at the Conference. It includes modelling of a flat-plate collector, the two "fully-mixed" storage tanks, two load heat-exchangers, storage tank losses, auxiliary furnace and control strategy. The model performs transient heat balance calculations, given hourly inputs for solar radiation, ambient temperature and space heating load. The storage medium in each tank is assumed isothermal, which permits closed-form heat transfer formulas to be used in the program calculations.

Figure 2 shows representative results for the performance improvement of the two-tank system over the one-tank system, using a single year of weather data for Boston, Massachusetts, and under the condition that the system has achieved steady-state performance over the year. The results show the trade-offs in performance for varying thermal storage capacities of the seasonal storage tank V_s, diurnal storage tank V_s' and for two tank insulation levels u_s and u_s'. A_c is collector area, T_R is room temperature and T_{max} is the maximum permissible temperature for either tank. Figure 2 shows a substantial improvement in overall performance for the two-tank system over the entire range of V_s values.

In addition to an analysis of sizing tradeoffs between V_s and V_s' for a number of U.S. locations, results will be presented at the Conference showing performance tradeoffs of collector area A_c versus total storage volume ($V_s + V_s'$), as well as the effects of changes in the collector heat loss coefficient u_c, and storage tank loss coefficients u_s and u_s'.

*Work supported by Division of Energy Storage Systems, U.S. Department of Energy.

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2. For a discussion of the effects of temperature stratification in solar-thermal systems, see, for example, "Analysis and Simulation of Stratified Heat Storage in Solar-Thermal Systems", by D.W. Connor and R.O. Mueller, Argonne National Laboratory Report ANL/SPG-4, June 1979.

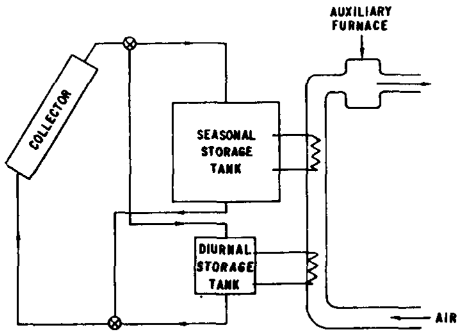


Figure 1. Schematic of Two-Tank Seasonal-Storage Solar Space Heating System

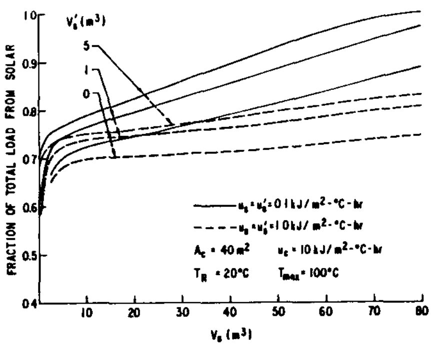
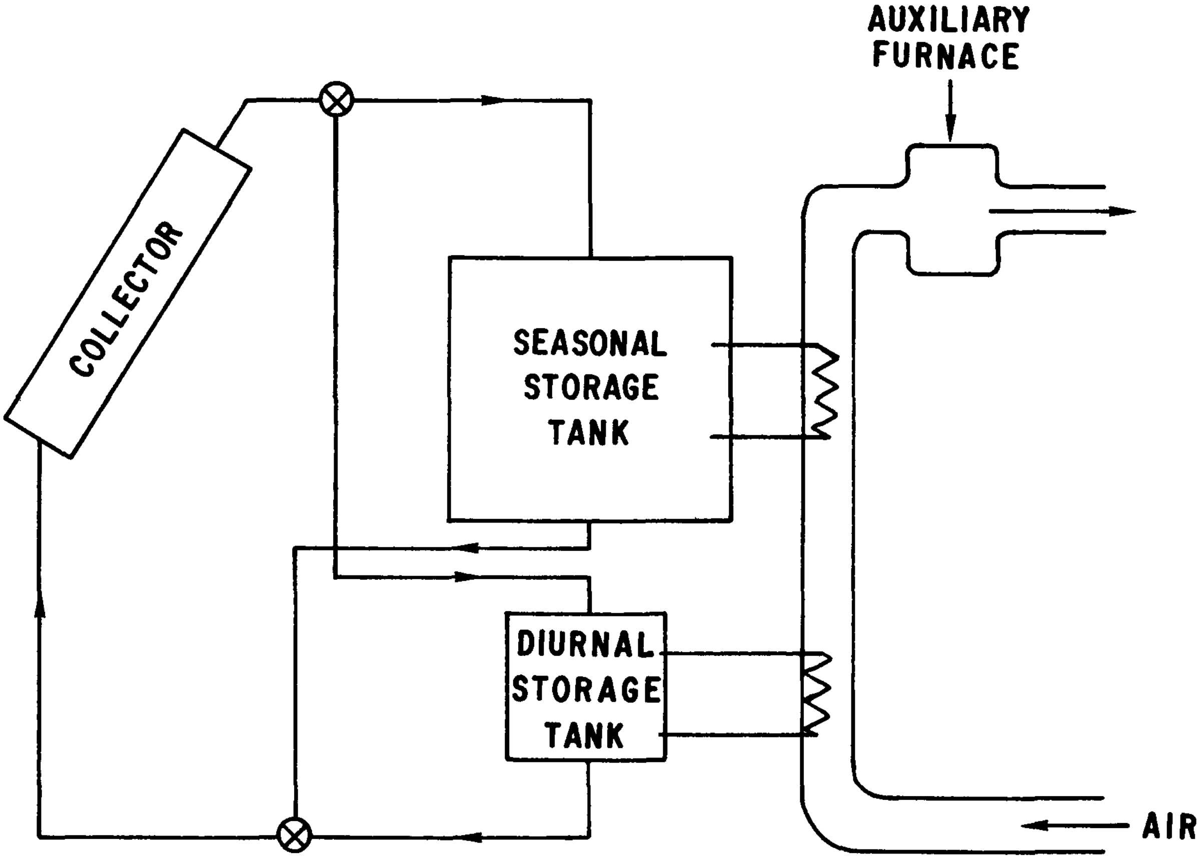
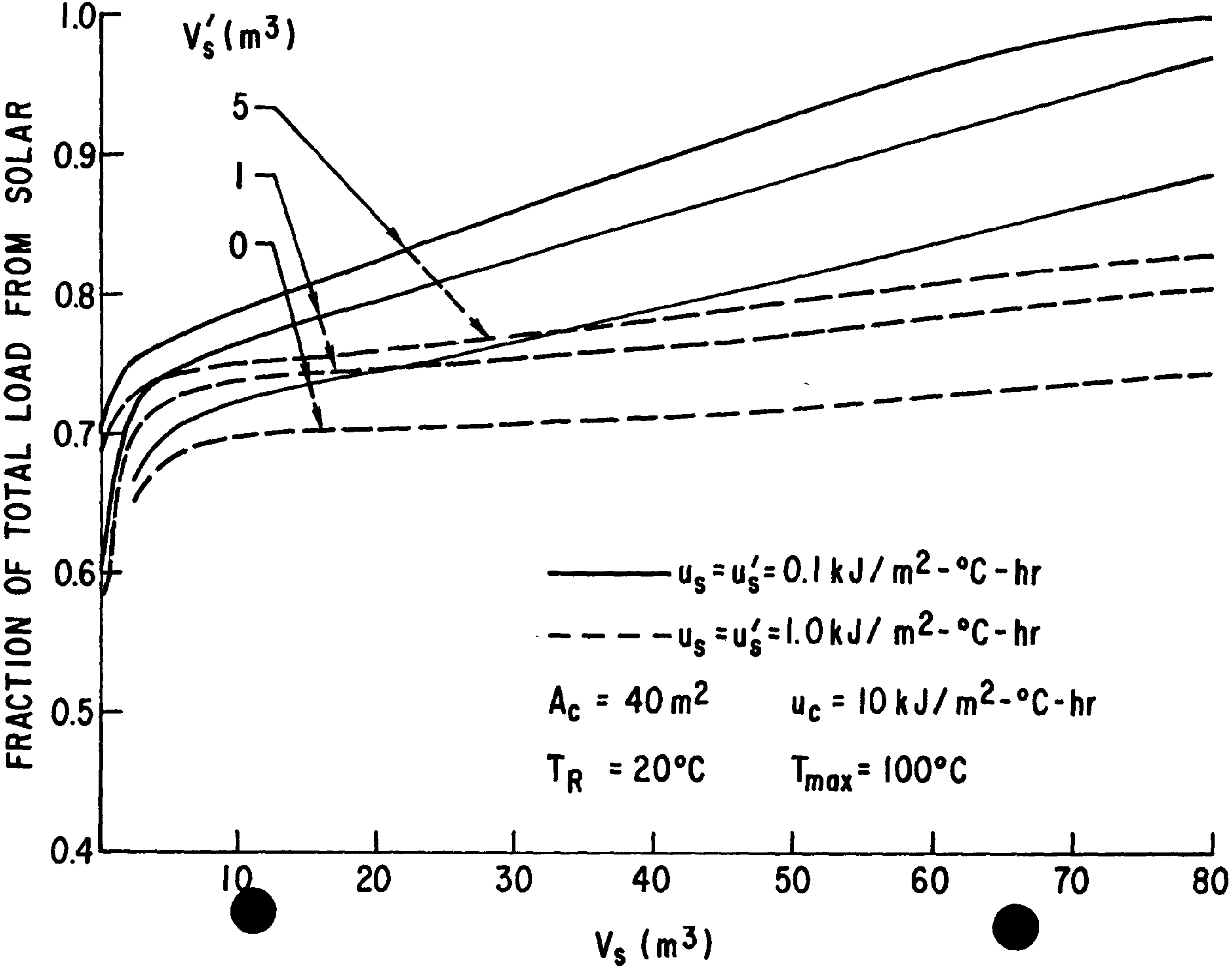


Figure 2. Comparison of Annual Performance of Two-Tank Versus One-Tank Seasonal Storage Solar Space Heating Systems


AUXILIARY
FURNACE
COLLECTOR
SEASONAL
STORAGE
TANK
DIURNAL
STORAGE
TANK
AIR


FRACTION OF TOTAL LOAD FROM SOLAR
V_s' (m^3)
5
1
0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
10
20
30
40
50
60
70
80
V_s (m^3)
$u_s = u_s' = 0.1$ kJ/m^2-°C-hr
$u_s = u_s' = 1.0$ kJ/m^2-°C-hr
A_c = 40 m^2
u_c = 10 kJ/m^2-°C-hr
T_R = 20°C
T_{max} = 100°C

THE CONSTRUCTION COST OF THERMAL STORAGE FOR SOLAR HVAC SYSTEMS

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EXTENDED ABSTRACT

During the last two years, Mueller Associates, Inc. (MAI), has obtained detailed storage system construction costs for 30 complete solar energy systems. Six of the systems were designed by MAI, and the remainder were the subject of cost analysis performed by MAI for the U.S. Department of Energy. The solar systems represent a mixture of new and retrofit systems, government and privately funded projects, heating, cooling, and hot water applications, and liquid and air systems.

The paper compares the materials, labor and insulation costs of these 30 storage systems. The cost data have been normalized to make the comparisons more meaningful. All costs have been converted to 1977 dollars. Because a variety of contractural structures were encountered, a fixed overhead and profit rate has been applied to the bare costs. The ratio of collector area to storage capacity varies widely among the systems studied. Therefore, in order to normalize for the different size systems, costs are expressed in terms of cost per unit storage capacity (dollars per kJ/^{o}C).

In addition to presentation of the collected cost data, the factors that impact costs are identified through statistical analysis of the data. These factors are discussed, and detailed descriptions of some of the storage systems are provided to help explain how the design affects costs. Areas for possible cost reduction are identified and discussed.

Storage system costs were found to be strongly affected by the type of storage vessel used. The types of storage vessel studied, in order of increasing cost per unit storage capacity, are as follows: unpressurized steel tanks, fiberglass tanks, pressurized steel tanks, rock bins, and residential water heater-type tanks. The location of the storage is also a primary cost factor. Exterior buried storage systems tend to be the most expensive, followed by exterior above-grade systems, and then by interior systems.

In most cases, the cost of insulation could be separated from the other materials and labor costs. The dependence of the insulation cost on R-value and type of insulating material is discussed. For those systems for which the cost data is available, the relative costs of different protective coatings is discussed.

The cost data are also analyzed to determine the extent of any economies of scale. "Economies of scale" is the term used when the unit cost of "large" systems is less than the unit cost of "small" systems. Statistical analysis of the storage system costs and capacities shows that the unit costs of solar storage do not decrease appreciably with increasing storage size. Economies of scale are not at work in this case.

Other factors that impact cost that are discussed include multi-tank systems, support techniques, installation techniques, delivery costs, and regional variations in labor and materials costs.

Many of the cost impacting factors also impact thermal performance and reliability. Unfortunately, the performance of a storage system is difficult to relate quantitatively to cost. While the cost/performance relationship for an entire solar system can be expressed simply as the ratio of total system cost to solar energy delivered to loads, no one energy flow can describe the thermal performance of a storage system. However, to aid solar system designers and researchers involved in reducing the cost of these systems, the cost/performance tradeoffs associated with the identified cost factors are discussed briefly.

THE VALUE OF THERMAL STORAGE IN SOLAR THERMAL APPLICATIONS

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The value of storage is the highest price a user would pay before an alternative becomes more desirable. For thermal storage in solar thermal power systems the value is shown to be variable. The key parameters are the application, the quantity of storage, the location (i.e., insolation), storage efficiency and the size of the collector field. Data on the value of thermal storage in storage coupled central receiver systems are presented. The data are calculated from two sources for an investor owned electric utility. Results from the two sources are very similar in magnitude, but significant differences exist. Data are included for buffer, diurnal, and long term storage applications.

SUMMARY & COMPARISON OF

DIURNAL STORAGE DATA SOURCES

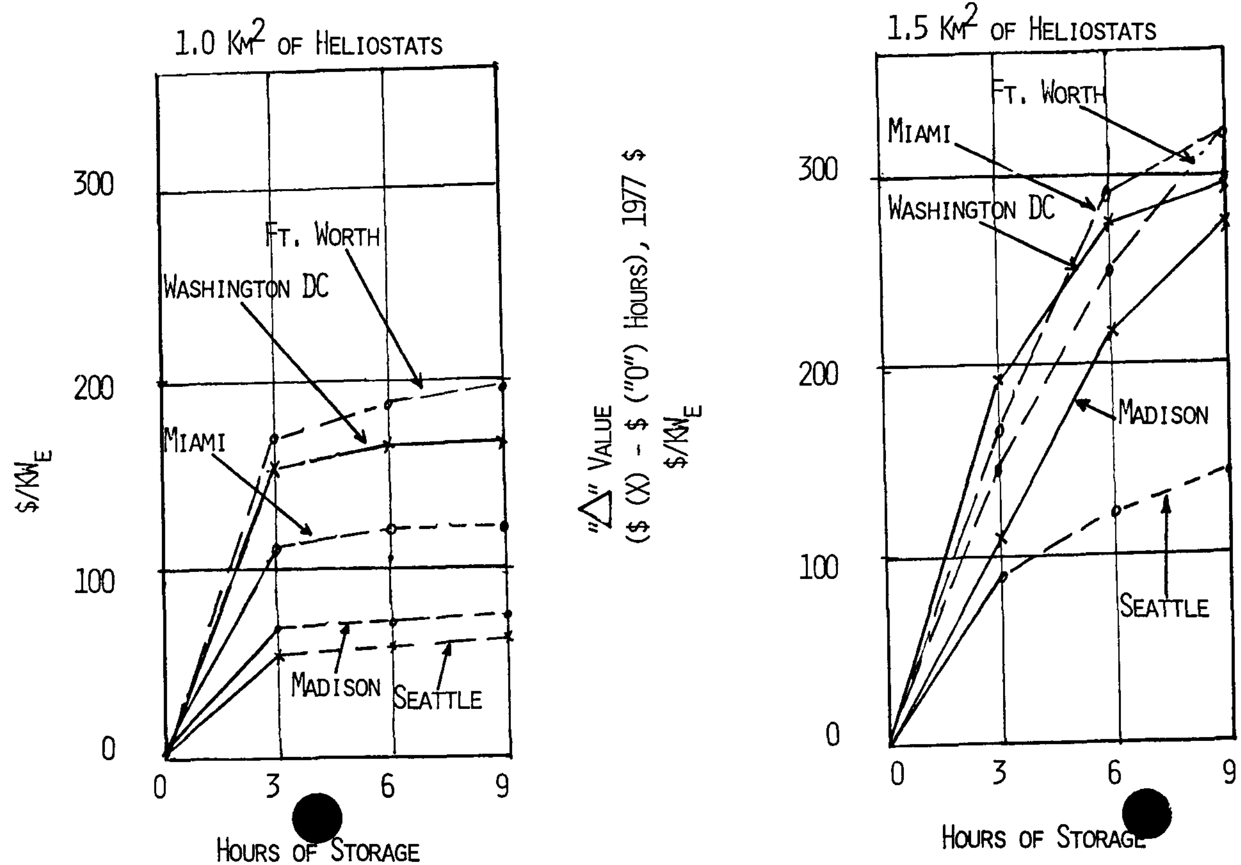
WRAP-AROUND VALUE(1) ($/KWH$_E$)

STORAGE CAPACITY	WESTINGHOUSE (1976 $) 1985 DATA (0.6 KM^2)	AEROSPACE (1977 $) 1990 DATA	
		1.0 KM^2	1.5 KM^2
3 HOURS	55 TO 160	22 TO 54	31 TO 62
6 HOURS	15 TO 50	12 TO 31	21 TO 48
9 HOURS	NO DATA	8 TO 22	16 TO 35

(1) GOALS FOR THERMAL STORAGE SHOULD BE EQUAL TO OR LESS THAN THIS VALUE, COST GOALS MUST INCLUDE THE OVERALL COSTS DUE TO 1) STORAGE POWER RELATED COST, 2) STORAGE ENERGY RELATED COSTS AND 3) OPERATIONS & MAINTENANCE (+ REPLACEMENT) COSTS. THE COSTS MUST ALSO INCLUDE NON-DIRECT FACTORS FOR A) CONTINGENCY & SPARES (15%) B) INDIRECTS (10%) AND C) INTEREST DURING CONSTRUCTION (15%) FOR AN OVERALL FACTOR (O.F.) OF 1.45 = (1.15) X (1.10) X (1.15); I.E., DIVIDE BY 1.45 TO DETERMINE ALLOWABLE DIRECT INSTALLED COST FOR THE SYSTEM.

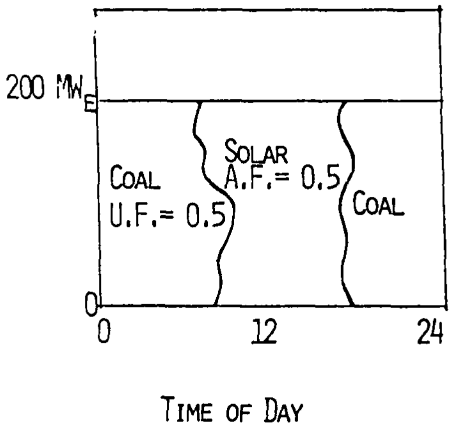
AEROSPACE VALUE DATA* AS $/KW$_E$

* FOR A 100 MW$_E$ PLANT: "BARSTOW" TECHNOLOGY CORRECTED TO 17% LEVELIZED FIXED CHARGE RATE (RATHER THAN 10%) AND LEVELIZED FUEL COST (RATHER THAN "SNAP-SHOT") FOR 1990 PLANT START-UP.



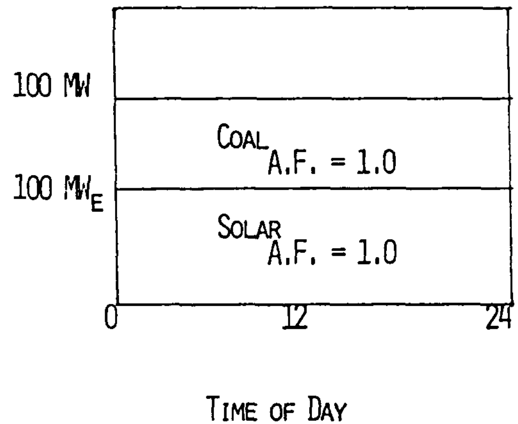
PRELIMINARY DATA
ON THE VALUE OF SEASONAL STORAGE
VERSUS COAL PLANS

COAL BACK-UP



VS

SEASONAL STORAGE



FOR ALBUQUERQUE (A.F. = 0.5 FOR SOLAR WITH 3 HR OF STORAGE)

VALUE OF STORAGE @ EFFICIENCY OF STORAGE

$964/KW_E	= 100%
$545/KW_E	= 62%
$314/KW_E	= 41%

* A.F. = AVAILIBILITY FACTOR
U.F. = ULTILIZATION FACTOR

A CYCLE LIFE TESTER FOR THE LONG-TERM STABILITY OF PHASE CHANGE MATERIALS FOR THERMAL ENERGY STORAGE

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EXTENDED ABSTRACT

INTRODUCTION

Phase change materials (PCM) present, on the one hand, some advantages over sensible heat substances for the storage of low-potential thermal solar energy. The PCM delivers its heat at almost constant temperature, and its relatively high heat of fusion reduces the volume of substance required (by a factor of 3 to 10, depending on the allowed temperature swing of the sensible heat substance [1]). On the other hand, PCMs such as salt hydrates and eutectic mixtures are not chemically simple substances. Before they can be considered for use in a thermal storage unit [2], one must ascertain, among other things, the long-term stability of their thermophysical or physico-chemical properties such as melting point, heat of fusion, supercooling, congruence of melting and decomposition. Since a PCM's lifetime use would involve several hundred or more freeze/thaw cycles, it would be convenient to study its thermal history on a greatly speeded-up scale. This can be done, for example, by differential scanning calorimetry (DSC) [3]. DSC however distorts the importance of supercooling since it uses rather small samples. We wished to simulate long-term use of PCMs using larger samples with a continuously-operating data-storing apparatus. This is described in the next section.

APPARATUS

The principle [4a] of the cycle life tester is simple and the apparatus is outlined in Fig. 1. The temperature of the PCM sample (50-100 cc) in a small bottle can be measured by means of up to seven thermocouples. The sample is successively melted and frozen by hot and cold streams of a glycol-water mixture. The streams are controlled by two-way valves operated simultaneously. A microcomputer is programmed to operate the valves and to record the thermocouple data continuously for as many cycles as desired. The cooling curve at any point in the sequence as registered by a thermocouple may be retrieved from the tape cassette storage and displayed for inspection. The thermal performance of the PCM is judged from, for example, the time dependence of the freezing

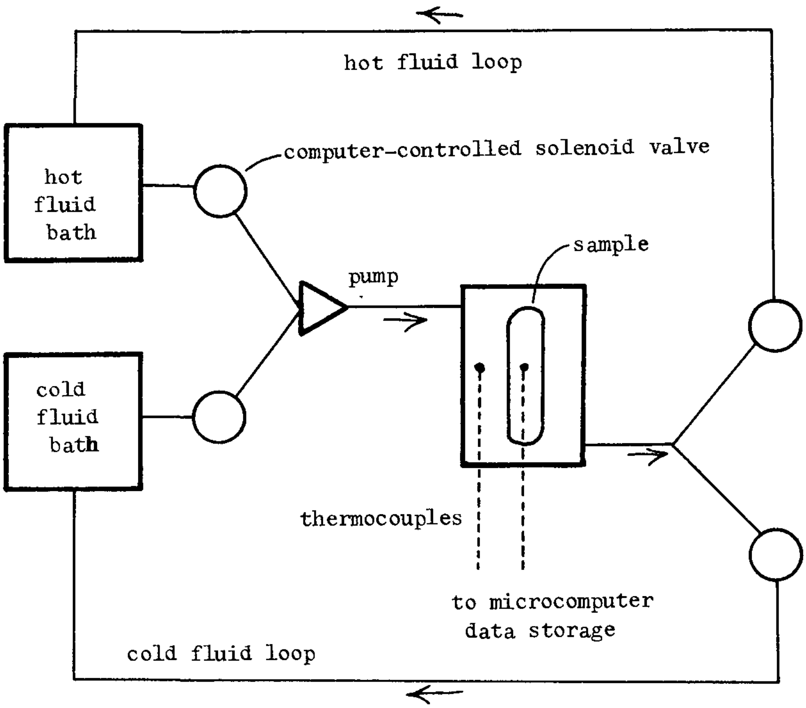

Fig. 1 Schematic of the cycle life tester

point, degree of supercooling and length of the temperature plateau. The sample may also be examined visually. Data from multiple thermocouples allows some information on stratification, rates of crystallization and thermal conductivity.

SUBSTANCES TO BE STUDIED

The apparatus was tested with a stable "reference" material such as paraffin wax or Wood's metal. The choice of PCMs for study was made from published surveys (e.g. [4b]) and individual suggestions: $H_2O + Na_2SO_4.10H_2O$ [5], $Mg(NO_3,Cl).6H_2O$ [6]. The apparatus can also be used, if desired, for nucleation studies [7, 8].

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SENSITIVITY ANALYSIS OF A COMMUNITY SOLAR SYSTEM USING ANNUAL CYCLE THERMAL ENERGY STORAGE

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EXTENDED ABSTRACT

INTRODUCTION

The objective of this research is to assess the sensitivity of design parameters of a community solar heating system having annual thermal energy storage to factors including climate, building type, community size, collector type and inclination, and soil conditions. The system under consideration uses a large, water-filled concrete, constructed tank for providing space heating and DHW. Although a number of systems have been constructed in Canada (1,2) and Sweden (3) and designs for others are underway in Canada, Sweden (4), and France (5), no such systematic study has yet been performed. This presentation details the technical analysis; an economic analysis is underway.

Incorporating an annual cycle thermal energy storage (ACTES) into a solar energy system has a number of advantages compared to diurnal storages. Energy can be collected during the summer for use in winter. Collector area can be substantially reduced because collector utilization is markedly improved. Well designed passive homes or building may further reduce requirements for solar collectors. Overall collection efficiency improves because more energy is captured when ambient temperatures are higher. Problems with collector stagnation in summer are all but eliminated. The economics of such a system are far more attractive for larger systems. As storage size increases the unit cost decreases. As well, the unit heat losses decrease and storage efficiency increases because surface area to volume ratio of the container decreases proportionately to increase in the radius. Only one back-up system, if any, is required for an ACTES solar system independent of the number of homes. Statistical averaging of demand in a community increases system reliability and may decrease overall power requirements. Operation and maintenance is a shared expense. Finally, a community system may have financing and tax advantages of a public utility.

Disadvantages of an ACTES solar system can be identified. An energy distribution system with all the incumbent thermal losses and water freezing problems, as would be the case in any community system, is required. Energy losses from storage are larger over a longer period of time. Capital outlays for such systems are larger per unit of storage than those for diurnal systems. Management of community ACTES systems must be an on-going effort by trained personnel.

METHODS

The analysis is based on a code developed at the University of Toronto by Hooper and associates (6). Altogether, 440 communities were sized. A method based on optimizing technical performance as determined by the above code (7). Three building configurations (single family, multi-family, and apartment complexes) and four community sizes (50,200, 400 and 1,000 units) were modeled in 10 geographic locations in the United States. Hourly weather data was used. In addition, all configurations were designed with flat plate and evacuated tube collectors both at two tilt angles (latitude and latitude plus ten degrees). Soil conductivity and therefore, storage efficiency was varied for one configuration. Fixed variables chosen for the study include transmission losses, building heat loss factor (used to calculate building heating load), DHW delivery temperature, maximum design tank temperature, building thermostat settings, amount of tank insolation and storage tank configuration. Details are presented in reference 6.

RESULTS

The results were being analyzed at the time of submission of the abstract. The paper in the conference proceedings will elaborate study results and conclusions

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PCM Thermal Energy Storage in Cylindrical Containers of Various Configurations

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EXTENDED ABSTRACT

Experimental measurements were made of the time variation of surface-average rate of heat storage (during melting) in and heat release (during freezing) from single, thin-walled copper cylindrical containers filled with a commercially available paraffin wax (Parowax, Esso). Figure 1 shows the effective heat capacity of the wax as a function of temperature as measured using a Perkin-Elmer Model DSC-1 Differential Scanning Caloriemeter according to the ASTM method. For the wax used the heats for solid-solid transition (λ_s) and solid-liquid transition (λ_f) were found to be 46 and 207 kJ/kg respectively. The heat capacities for the liquid and solid phases were nearly independent of temperature and had values of 2.09 kJ/kg K and 2.76 kJ/kg K respectively. The effect of repeated thermal cycling (melting and freezing) on λ and c_p of the wax was found to be negligible.

The PCM container shapes studied included three lengths of plain circular, plain square and internally partitioned copper tubes of circular cross-section. The containers were sealed and insulated at the bottom, and immersed perfectly vertically in a concentric tube (insulated from the outside) with water flowing axially through the annulus, entering the exchanger at 60 °C and 70 °C for the melting cycles and at room temperature for the freezing cycles. The effect of the following parameters on the rate of heat storage and release was studied: water flow rate through the annulus, shape of the cylinder, height of the PCM column in the container and the temperature of the heating water. A few typical results are shown in Figures 2 through 4. In general the results are in agreement with the conclusions of Marshall (1).

The heat transfer measurements revealed importance of natural convection in governing the heat flux variation with time during melting. This was confirmed in flow visualization studies using tracer particles in the wax contained in

transparent plexiglas cylinders immersed in a constant temperature bath. The influence of natural convection is much less significant in the case of freezing, as may be expected.

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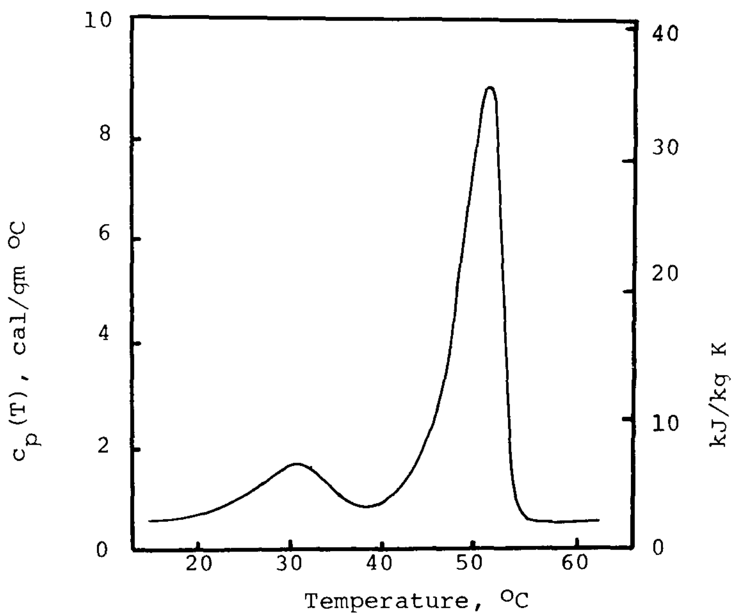

Fig. 1 Effective heat capacity of PCM used

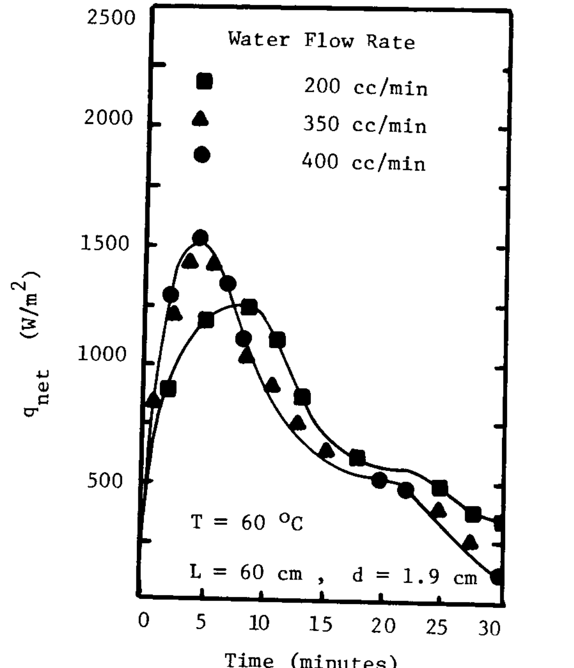

Fig. 2 Effect of water flow rate on q_{net}

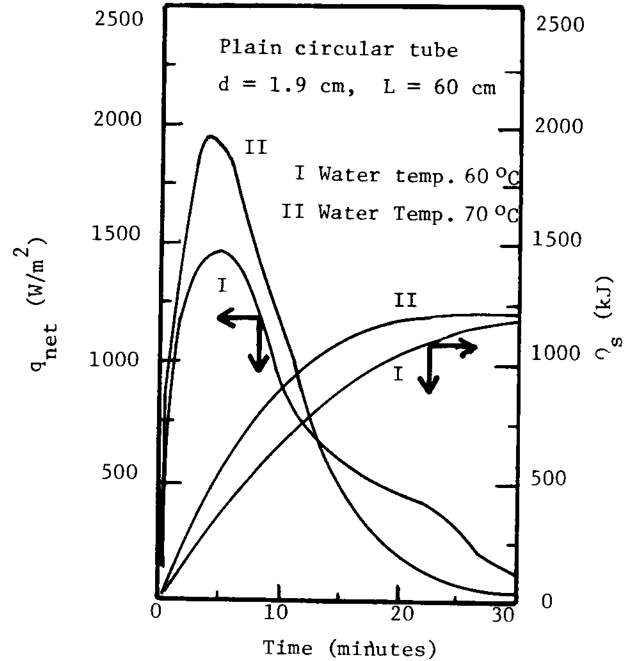

Fig. 3 Effect of water temperature

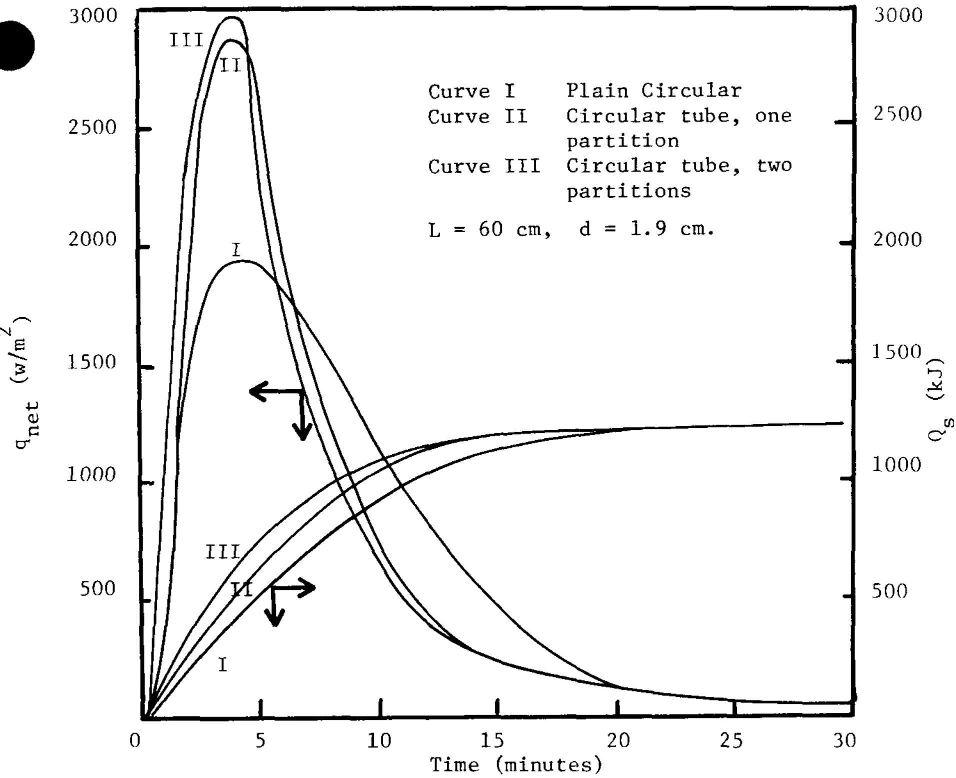

Fig. 4 Influence of container geometry on thermal storage

PHYSICAL AND CHEMICAL PROCESSES FOR LATENT HEAT STORAGE AT LOW TEMPERATURES

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EXTENDED ABSTRACT

Latent heat storage systems utilize physical or chemical processes, which run endothermic above a transformation temperature and run exothermic below this transformation temperature. The endothermic reaction is used to load the store and the reversed exothermic reaction is used to restitute the stored energy when needed.

In this report a survey on physical and chemical processes will be given, which seem to be suitable for latent heat storage between 20° C and 250° C. As a high heat storage capacity per unit of volume is desirable the survey is limited to processes in or between condensed phases. A classification is made in processes with one, two, three and four components. The number of types of reactions suitable for latent heat storage increases very considerably in three and four components systems. Therefore, only those types of reactions have been presented in three and four components systems, which seem to be very suitable for low temperature latent heat storage.

The types of reactions investigated in this report are:

1. One Component Systems
1.1. Solid-liquid transitions
1.2. Solid-solid transitions
1.3. Liquid-liquid transitions

2. Two Components Systems
2.1. The components are completely miscible in the liquid phase
2.1.1. The components form a eutectic mixture
2.1.2. The components form mixed crystals with an extremum of melting temperature
2.2. A gap of miscibility exists in the liquid phase
2.2.1. The components are partially immiscible
2.2.2. The components are completely immiscible

2.3. Polymorphic transitions
2.4. The components form a compound
2.4.1. The compound melts congruently
2.4.2. The compound melts incongruently
2.4.2.1. Decay in a solid and a liquid phase
2.4.2.2. Decay in two liquid phases
2.4.3. Formation and decay of a compound in the solid phase

3. Three Components Systems
3.1. Eutectic mixtures
3.2. The components form compounds
3.2.1. Binary compounds
3.2.2. Ternary compounds

4. Four Components Systems
4.1. Solid-liquid transitions
4.1.1. Eutectic mixtures
4.1.2. Systems with compounds
4.2. Reciprocal salt pairs

Transformation temperatures and enthalpies of reaction of special reactions, as far as known, are presented for each of these types of reaction.

Own experimental results are reported for two reciprocal salt pair systems. These data consist of the temperature of transition, the enthalpy of reaction, specific heat and heat of solution above and below the transition point, heat storage capacity within a certain temperature interval, heat storage capacity during a larger number of heating and cooling cycles, solid and liquid density at the transition point, compatibility with containment materials and costs of the materials in technical purity and in large quantities.

Several of the presented types of reaction are not suitable for latent heat storage. Other types of reaction are, or seem to be, suitable for low temperature latent heat storage, namely:

- solid-liquid transitions of
  -- one component systems,
  -- two components eutectic systems,
  -- two components mixed crystals systems with a minimum of melting temperature,
  -- congruently melting compounds of two components,
  -- incongruently melting compounds of two components (e.g. salthydrates),
  -- three components systems with binary eutectic points,
  -- three components systems with ternary peritectic points,
- double conversion of reciprocal salt pairs.

Further investigations are necessary for all these types of reaction and for the identification of special systems. With this, the number of latent heat storage systems can be increased essentially and the interesting temperature range can be covered more completely.

ACTIVE HEAT-PIPE FILLED WITH GLYCOL-WATER SOLUTION

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EXTENDED ABSTRACT

Based on the experience gained so far, a new heat-pipe greater than the first [1,2] was constructed by the authors and has been studied experimentally. This type of heat pipe contains active porous material, which by decomposition first gives up water and then undergoes a change in its porous. The new pipe is of cylindrical form and has a 600 mm length and a 35 mm diameter. The active porous material is a specially prepared inorganic compound with a 63% porosity. The circulating liquid is a glycol-water solution.

Copper is the tube material. A glycol-water solution has been introduced in the interior of the heat pipe and it has saturated the porous medium.

The yield of the heat pipe is given by the following relation

$$n = \frac{Q}{W} \qquad (1)$$

where, Q = the amount of heat removed from the condenser per unit of time, n = the yield of the heat pipe and W = the power supplied to the evaporator.
The yield of the heat pipe has been calculated from Eq. (1). Properties of this active porous medium as porosity, thermal conductivity, density, permeability, height of the capillary rise have been measured or evaluated.

The differential thermal analysis has shown two endothermal peaks at 170°C and 190°C respectively. In the thermogravimetry pattern it has been clearly shown that a crystalline structure has appeared.

It has been also shown that the porous medium decomposes reversibly during a heat cycle.

After introduction of the active porous medium in the heat pipe the experiments lasted for 650 hours.

To obtain measurements on the heat pipe, we have used thermocouples chromel-alumel. The flowrate of the cooling water of the condenser is measured with a flowmeter. Air temperature has been measured with a thermometer.

The heating of the heat pipe evaporator is provided by an electric resistance.

The heat pipe has a pressure socket at the end. The vacuum, which was obtained by a water pump, was measured by a manometer.

Experiments were performed during, usually 2 days. For inclination a = -45 of the axis of the heat pipe in connection with the horizontal plane, we studied experimentally the relation between the yield of the heat pipe in steady state operation and its temperature difference between evaporator t_k and air t_a. The relation between the yield and the above temperature difference versus the supplied electric power per unit of heat pipe exterior surface has also been studied.

From the experiments we observe that the relation of yield to $t_k - t_a$ and to $(t_k - t_a)s/W$ is not linear. These results do not agree with Ortabasi's [4].

a. The inclination of the heat pipe in [4] was 11.5° whereas in our experiments 45°.

b. The porous material which filled the heat pipe in 4 was inactive whereas in our pipes it was active.

c. The yield of our heat pipe is much better than that of [4].

Comparing the above experimental results with [4] and [3] we observe that if we increase $t_k - t_a$ the yield in [3] decreases rapidly, the yield in [4] decreases slower and in our work it increases.

From outside the heat pipe was isolated.
The overall losses are estimated to be $U_L = 3.2$ watt/m^{2}C for $t_k = 50^oC$ and $t_a = 20^oC$.

Consider now a heat pipe placed in the interior of a glass tube of 100 mm exterior diameter under vacuum and suppose that half of the interior surface of the glass tube is covered by a mirror [4] and that $\varepsilon_3 = 0.057$ (aluminum).

After a preliminary calculation we found that the losses due to the isolation correspond to the intermediate or continuous area with a Knudsen number $Kn < 0.887$ and $p > 10^{-3}$ mm Hg.

So, if the heat pipe were put in a glass tube under vacuum, it would have for $p > 10^{-3}$ mm Hg

$$U_L \simeq 3.2 \text{ watt/cm}^2\text{C}$$

Comparing this result with the result of the vacuum in Ortabasi's experiment ($10^{-5} \sim 10^{-6}$ mm Hg), we observe that we probably can construct a heat pipe with satisfactory yield with a vacuum corresponding to a pressure greater than 10^{-3} mm Hg. We hope it will be easier to conserve such a vacuum in a design of this sort [5].

An experimental investigation on that matter must follow.

CONCLUSIONS

Using the previous experience to the study of a heat pipe with active porous material, we constructed a longer heat pipe with perspective of making, afterwards, its length even greater.

This heat pipe shows higher yields, if compared with other heat pipes and it is possible to use it as an element of a flat plate collector or concentrator.

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SESSION 4B

SOLAR HEATING AND COOLING II

ENGINEERING DEVELOPMENT OF A HYCSOS CHEMICAL HEAT PUMP

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EXTENDED ABSTRACT

Argonne National Laboratory (ANL) is developing a hydride conversion and storage system (HYCSOS) that is capable of thermal energy storage, space heating and cooling. As a thermal storage medium, metal hydrides provide a high-energy density; however, the economics of such a system are currently unattractive. As a chemical heat pump, a metal hydride system offers the promise of using solar energy, waste heat, natural gas and other energy sources to provide space heating and cooling. The incorporation of an electrical power generation cycle is also a possibility.

The HYCSOS chemical heat pump utilizes the heat of absorption and desorption of hydrogen from different metal hydride beds to provide space heating or cooling. In its simplest form, a hydride heat pump consists of two different hydride beds that are interconnected to allow hydrogen gas transfer between them. The heat pumping action of the system involves a four-step process:

1. High temperature heat is applied to the first bed causing it to desorb hydrogen which flows to the second bed where it is adsorbed at an intermediate temperature. The heat of absorption is rejected to the building (heating mode) or to the outside atmosphere (cooling mode).

2. The two beds are cooled -- the first to an intermediate temperature and the second to a low temperature.

3. Heat from the building (cooling mode or from the outside atmosphere) is added to the second bed to desorb hydrogen which then flows to the first bed where it is absorbed. The heat of absorption is rejected to the building (heating mode) or to the outside atmosphere (cooling mode).

4. The two beds are then heated back to their original temperatures to complete the cycle.

A laboratory test facility has been constructed and used to demonstrate the feasibility of the HYCSOS chemical heat pump. The majority of the work on HYCSOS has been on hydride material studies. Ternary alloys of $LaNi_{5-x}Al_x$ have been developed to provide materials with hydrogen dissociation pressures that can be varied by almost three orders of

magnitude.

This paper will concentrate on the engineering development of a heat pump which uses a unique tubular hydride heat exchanger. This design features a large number, about 150, of individual tubes. Each tube contains a high temperature hydride at one end, and a low temperature hydride at the other end. The central portion of the tube is designed to allow hydrogen to flow freely between the ends, and yet prevent the flow of heat between the ends.

This proposed design has several advantages including:

. no hydrogen valves required

. high reliability due to the large number of independent heat exchanger elements

. potentially high coefficient of performance (COP) due to a unique method of heating and cooling the hydride beds

. potentially high COP possible by cascading units for a gas fired application.

. simple control system and minimal valves outside of the unit

The current status of this design effort including the systems engineering and experimental studies will be discussed. Also to be discussed will be the integration of this concept into a number of applications including: gas fired heating and cooling, solar assisted heat pump, automobile air conditioning, and truck refrigeration.

ANALYTICAL AND EXPERIMENTAL EVALUATION OF SOLAR ABSORPTION AND VAPOR COMPRESSION RESIDENTIAL COOLING SYSTEMS

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EXTENDED ABSTRACT

Results from the two-year experimental evaluation of solar absorption and vapor compression cooling systems are presented. The systems are part of a solar experimental program in progress at The University of Texas at Arlington's Solar Energy Research Facility (UTS/SERF). The facility is a 1550 square foot residence with a passive solar design. The solar system consists of the following components: Four hundred and twenty square feet of concentrating collectors, 520 square feet of flat-plate collectors, a three-ton lithium-bromide Arkla absorption air conditioning unit, a Lennox two-speed water to water heat pump, and a thermal storage system. The solar systems operation modes are:

- direct solar heating
- heat pump heating
- absorption cooling
- heat pump cooling
- domestic hot water heating

An 8 KW_{pk} photovoltaic system is also in operation since November, 1978. This system consists of 240 photovoltaic modules. Electric power generated from the photovoltaic system is used on demand, thermally stored, or fed back to the utility power lines. Results on the UTA/SERF system operation will be presented in detail at the conference.

SOLAR AIR CONDITIONING IN A HOT ARID CLIMATE

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EXTENDED ABSTRACT

A hot arid climate has the advantage of having a lot of solar radiation with a minimum amount of humidity, 17-40%. The solar air conditioning is an application which matches the radiation intensity and since the intensity of solar radiation is high in arid zones, the solar air conditioning works very well.

If the cost is not a major problem, then electrcity is generated either by a thermal process or photovoltaic conversion and used to operate a conventional air conditioning unit. This is being done in Saudi Arabia at the experimental farm of the Ministry of Agriculture near the city of Riyadh. But because of the high cost of electricity generation, and the reduction of efficiency in this method, a direct cooling cycle is the ultimate. Therefore two cycles are described here.

Figure 1 shows the basic absorption system for the Arkla Solaire Unit. It contains the working fluid which is a solution of refrigerant, water and absorbent, lithium bromide (Li-Br). The solution is harmless and non toxic. It is hermetically sealed. Heat is added to the solution in the generator from $56m^2$ solar heated collectors (sequence 2) which vaporize the refrigerant so that a weak mixture in refrigerant concentration is left behind. The refrigerant then condenses into a liquid in the condenser (sequence 3). The liquid refrigerant is then expanded from a high pressure portion of the system, left hand side, (generator and condenser) into the low pressure evaporator wherein vaporization of the refrigerant takes place (sequence 4), and hence a closed water loop with anti-freeze solution, 10% Ethylene Glycol, is circulated. This is normally called the chilled water loop. An air handling unit is used to blow air on the chilled water coils and air conditioning of the room is achieved. In sequence 4, the evaporation of the regrigerant produces the chilled water. The vapour refrigerant is now reunited with the absorbent mixture from which it was initially obtained (sequence 5). This reunion is an exothermic reaction and heat must be removed from the absorber to maintain its temperature at a sufficiently low value to assure a high chemical affinity between the water and the lithium bromide solution. The solution is now rich with refrigerant, water and it can be pumped back into the generator to repeat the cycle (sequence 1). Figure 2 shows a sketchmatic diagram of the whole arrangement.

Figure 3 shows a Rankine engine of the same size as that of Figure 1, 3-tons. The cycle is well illustrated. Figure 4 shows a passive tower cooling in Bahrain. This used to be a common feature of all buildings until 1940 when oil was discovered and the cost of electricity became cheaper.

In conclusion, passive air conditioning is cheap and requires no machines or labour. Using solar energy with an absorption cycle machine is more practical and slightly cheaper than a Rankine-cycle machine when the range is less than 5 tons. In the range of 10 tons and above the Rankine engine is cheaper. This paper contains several performance curves and recommendations.

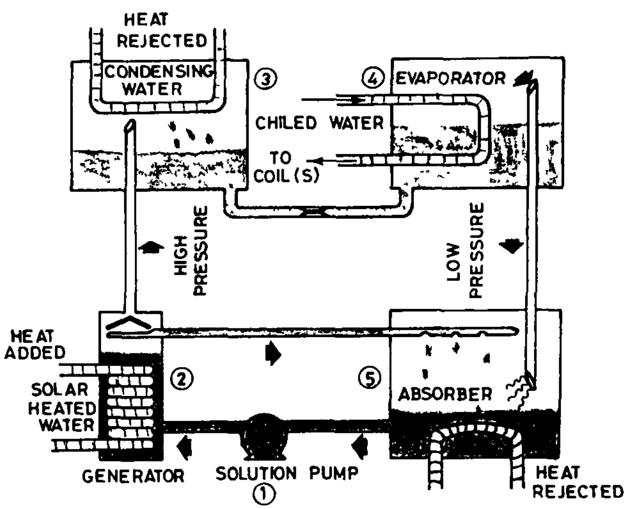

Fig. 1 - Li-Br Absorption Unit

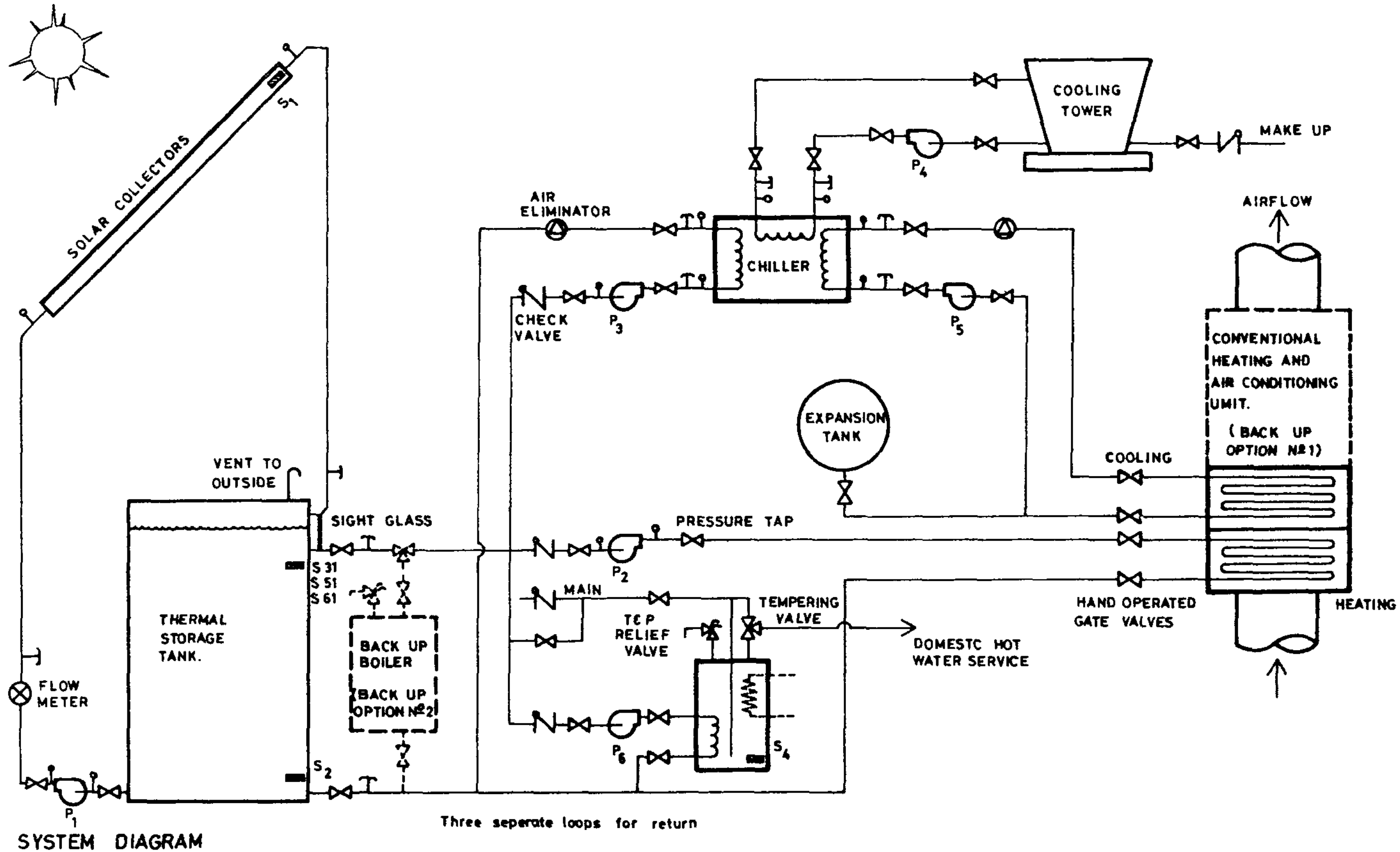

Fig. 2 - An Absorption System

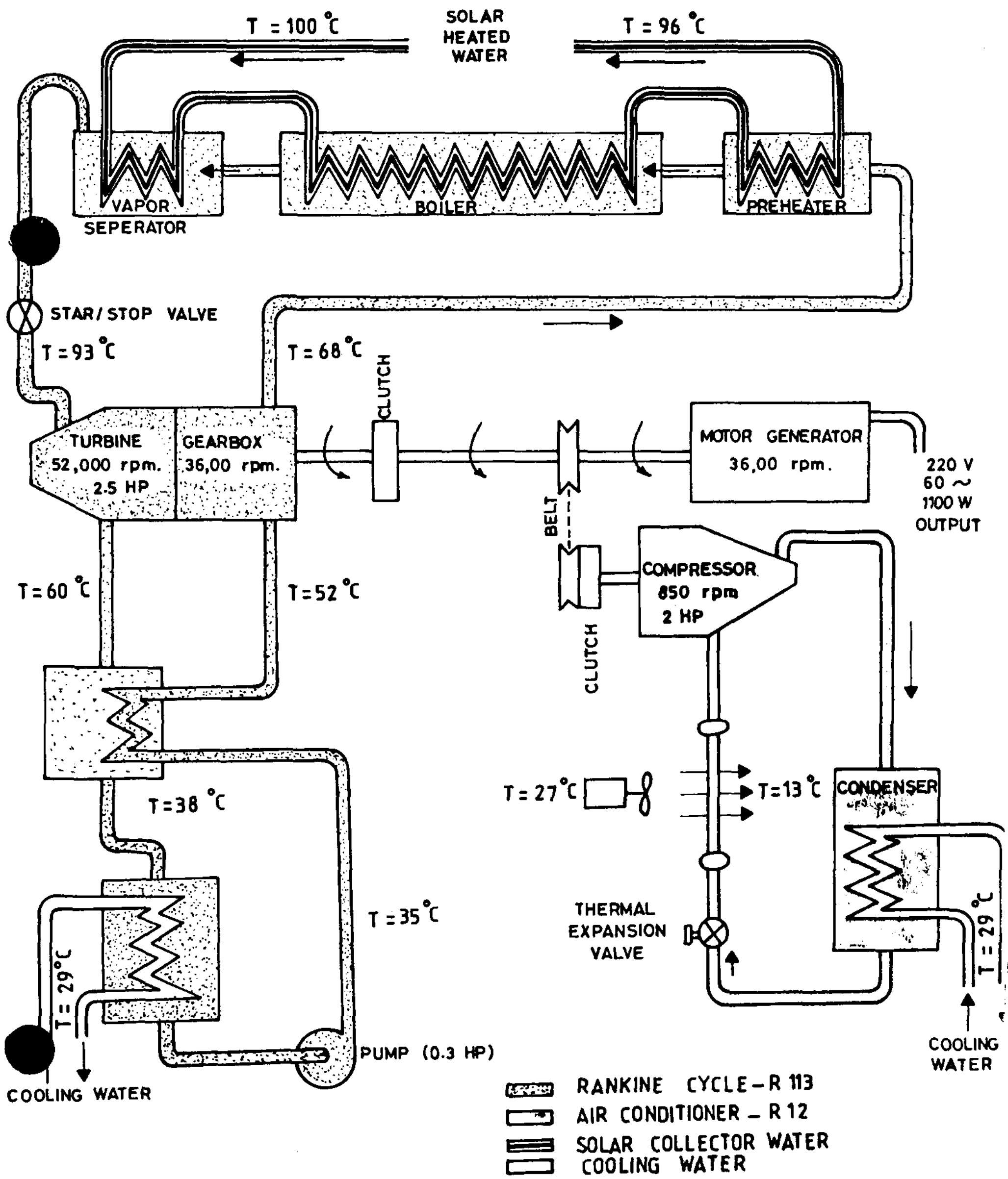

Fig. 3 - Rankine Solar Air Conditioner

Fig. 4 - Passive Tower Concept

THE SERIES SOLAR HEAT PUMP AND ENERGY CONSERVATION

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EXTENDED ABSTRACT

INTRODUCTION

One of the areas in which solar energy can realistically serve as an alternate energy source on a technological basis is the space heating of buildings. Significant amounts of fossil fuel saving are possible, but progress toward utilization has been slow because of high system costs, particularly due to that of the collectors, relative to competing currently available and future alternatives. The series solar heat pump offers the potential to retain the energy conservation capability of a direct solar heating system while improving the market competitiveness. This potential lies in the fact that the series solar heat pump works in conjunction with low temperature collection devices which can be markedly cheaper than direct heating collectors, while producing high Coefficients of Performance (COP) due to relatively high source temperatures. Moreover, the presence of the heat pump also provides capability for space cooling, load management (with storage), and use of a back-up heat source that can be processed through it. Solar heat pumps are not now cost-competitive with conventional heating systems (e.g. gas furnace, air/air heat pump), but a number of simulation studies have shown them to be more cost-attractive than straight solar heating systems for much of the United States; and because of its energy saving potential a serious developmental effort to address the specific problems which, if solved satisfactorily, can make the series solar heat pump competitive in the near term.

Brookhaven National Laboratory (BNL) as technical support laboratory to the U.S. Department of Energy, Office of Solar Applications in the area of solar usage with heat pumps is conducting in-house experimental and analytical projects and is technically monitoring a program of industrial R&D contracts which point toward development of practical solar heat pump systems - with strong emphasis on the series configuration. This paper describes the performance and energy conservation aspects of these efforts.

CONCEPT AND THEORY

A basic series or Solar Assisted Heat Pump (SAHP) system is shown in Figure 1. Low temperature flat-plate collectors supply heat to a large thermal storage reservoir, which is the source for an electrically driven vapor compression heat pump. The collection/storage temperatures range from 40 to 110°F (4 to 40°C) and are boosted to space heating level by a heat pump designed to use them undiluted to produce high evaporating temperatures and

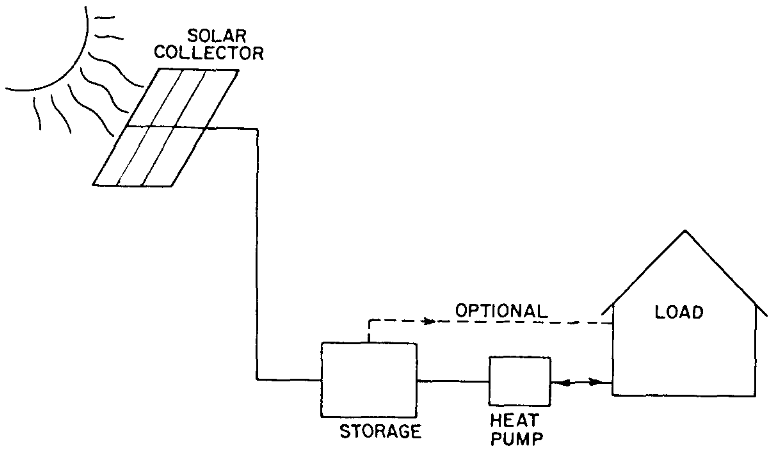

Fig. 1. Basic Series Solar Heat Pump Schematic

attendant high COP (and capacity). Thus, the inherent thermodynamic property of the vapor compression cycle to yield increasing COP (heat delivered divided by work in) with increasing evaporating temperature, following the Carnot trend, is exploited. High COP denotes high solar fraction and conservation of non-renewable energy, the overall measure being Seasonal Performance Factor (SPF), i.e. the total heat supplied to the load divided by purchased energy, with auxiliary heat included. Auxiliary is required when there is insufficient solar energy available to supply the heat pump, and its use must be minimized or its COP reasonably high in order to achieve a good SPF and take proper advantage of the series concept. Solar starvation in deep winter has been identified as the principal problem of SAHP systems; if it can be suitably overcome SPF's on the order of 4 are attainable.

Since solar collection for the SAHP system occurs at temperatures that are not far above ambient, good efficiencies are attainable with collectors that have high loss coefficients and are, thus, potentially inexpensive. Additionally, low temperature storage can be inexpensive and make use of the earth or available water as part of the medium. In the cooling mode solar energy does not assist, but opportunistic use of system components can contribute to improve efficiency.

HEAT PUMP PERFORMANCE - EXPERIMENTAL RESULTS

A systematic experimental study of heat pump performance at high source temperatures representative of solar input is being carried out in the BNL Solar Laboratory using a specially constructed simulator. Test results using a residential size Laboratory Model Heat Pump, which was designed and assembled from off-the-shelf components, have been obtained which clearly demonstrate a substantially increasing COP with evaporating temperature by using compressor speed modulation, sufficiently large heat exchangers, and proper expansion device [1]. Steady state cycle COP's from 3.5 to 9.7 were measured in the evaporating range from 50 to 100°F (10 to 38°C), which translate to net COP's of 3 to 7 when parasitics are included. These results are summarized in this paper and additional recent data corresponding to alternate components and extended test conditions are presented. Results obtained by manufacturers under DOE SAHP hardware development contracts are also discussed.

COLLECTORS

Collectors for the SAHP must take advantage of the low temperature requirements to allow simple, single glazed (or unglazed), configurations costing less than $5/ft^2 installed to be used. Site assembled, structure-integrated configurations, suitable durable plastics, and passive-like devices are good candidates for cost effectiveness. BNL is studying heat pump collectors in-house and a brief summary of this work together with general requirements of SAHP collectors is given.

SAHP SYSTEM PERFORMANCE

Based on experimental results it appears that high COP performance at high solar source temperatures can be achieved by the heat pump component without major difficulties. Applying this high COP performance effectively to a practical SAHP system is a more challenging problem because of the need to supply sufficient solar energy to (a) obtain suitably high source temperature a significant fraction of the time and (b) avoid solar depletion so that excessive auxiliary heating is not required. To accomplish this there must be either a suitably large collector area and storage volume, the use of relatively efficient auxiliary (not electric resistance heat at COP of 1 which has been assumed in many simulations with discouraging results), or some trade-off combination of the two approaches. The auxiliary can be an alternate heat pump source such as the earth, natural or man-made water reservoir, or the air ("dual-source"). Earth coupling is particularly interesting as it allows storage of otherwise unused summer/fall solar heat in the ground and is a sink for efficient cooling reject, and it is being studied in detail at BNL. Computer simulations at BNL and in DOE contract efforts have addressed SAHP performance aspects for many geographic areas of the United States, and these results are discussed in the paper and applied to interpreting the various possible successful SAHP system designs in different climates.

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BI-COOLANT SOLAR COLLECTOR WALL FOR BUILDING HEATING AND COOLING

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ABSTRACT

While there exist numerous solar collector types which have been developed to this date, a single working fluid has normally been employed in the primary loop of these collectors; the second working fluid, if employed, flows in the secondary loop of a heat exchanger to secure the proper fluid form needed in the specific heating or cooling load. With the incorporation of a heat exchanger, however, the overall thermal efficiency is lowered, making the system more expensive at the same time.

A collector which employs two working fluids, on the other hand, offers the following advantages:

(1) When both sides of the collector plate (wall) are utilized as heat transfer surfaces, the overall heat transfer coefficient for removal of solar energy is greatly increased.

(2) With proper combinations of two fluids, the versatility of the system is greatly enhanced. The energy transfer in both liquid and gaseous forms is possible to various types of loads concurrently without the intermediate heat exchangers.

(3) The elimination of hot spots in the system via the high collector efficiency would make the system most suitable for medium temperature applications such as building heating and/or cooling, as well as hot water supply.

(4) The bi-coolant collector is simple in its basic concept, and the total system based on the concept can be flexible in its

design. Both forced or natural convective flow may be used, depending on the insolation level and the type of specific application. The construction of the unit can be simpler and less costly compared to other hybrid units which are currently being developed.

Although the "bi-coolant" collector may be used in various ways, one excellent application is found in its possible integration into a "bi-coolant Wall". The inner working fluid, during the heating cycle, flows upward toward the overhead accumulator via thermo-siphoning (passive mode), and supplies the hot fluid to the load from the accumulator. The outer fluid--e.g., air--flows also upward, during the heating cycle, to supply hot air to the rest of the building. In case nocturnal cooling is required, the inverse thermosiphon effect is achieved via Gandenzi-type bypass channels (Reference 1) with the window left uncovered. Unlike the Trombe wall (Reference 2), however, much of the hot water is accumulated in the overhead accumulator, which is heavily insulated, and the possible reflection toward the window is also minimized.

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SOLAR AIR CONDITIONING WITH SOLID ABSORBENTS AND EARTH COOLING

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EXTENDED ABSTRACT

Open cycle dessicant cooling systems utilize the principle of dessicant drying assisted by evaporative cooling to maintain a desired environment in a conditioned space. Shelpuk (I) has reviewed the state of development of absorpton/desorption processes showing that a very attractive alternative would be among those equipments based on a recyclable air dessication process using silica gel.

This paper deals with a study carried out on an air cooling system to be used in a warm humid tropical climate as existing in most of the Venezuelan territory (2).The main objective is to develop an inexpensive air cooling equipment in which the only moving parts are the air fan and the hot water pump servicing the solar collectors.The key issues of such a device are:

- the amount of moisture which can be removed by the dessicant when it is cycled between high and ambient temperatures,
- the minimum dew point which can be achieved.

In the design proposed here we make use of a natural heat sink represented by the earth and flowing underground water whose average temperature never exceeds the local annual mean temperature. The air used in the process is cooled and predryed in an air-underground water heat exchanger in order to remove up to 40% of the initial moisture content.A portion of this air is then sent to the dessicant column for further remotion of the moisture, and then cooled regeneratively by exchanging heat with the other portion of the cold predryed air.At this stage the air can either be supplied to the building or further be evaporatively cooled. As the equipment operates alternatively with 2 dessicant columns, the desorption of the saturated dessicant is achieved simultanously by using the air which has been preheated in the regenerative heat exchanger. Before entering the drying column, this air passes through a counterflow heat recouperator and is boosted to its final desorption temperature by using solar heat.

Table I shows the design operating conditions which are based on the city of Maiquetia, Federal District, Venezuela; Table 2 reports the geographical and insolation characteristics of this location. Figure I shows the

flow diagram of the system and figure 2, the process lines on a psychrometric chart. The equipment has been designed to provide I50 M3 per hour of air at 25 ºC and 60 % relative humidity.

The bidding for the construction of this experimental installation is in process.

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Table I : Design Operating Conditions

Temperatures:	Outside ambient	:	35 ºC
	Inside ambient	:	25 ºC
	underground water	:	23 ºC
Relative Humidity	Outside ambient	:	80 %
	Inside ambient	:	60 %
Air Flow Rate	Total	:	380 $Kg.hr^{-I}$
	Useful	:	I80 $Kg.hr^{-I}$

Table 2 : Geographical and Insolation Characteristics

Latitud : I0º 36'N
Longitud : 66º 59'W
Altitud : 22 m
Mean annual temperature : 26.2 ºC
Average maximum temperature : 29.6 ºC
Annual sunshine hours : 2700 hr
Mean daily global irradiation : 20.6 $MJ.m^{-2}$
: 492 cal $cm^{-2}day^{-I}$

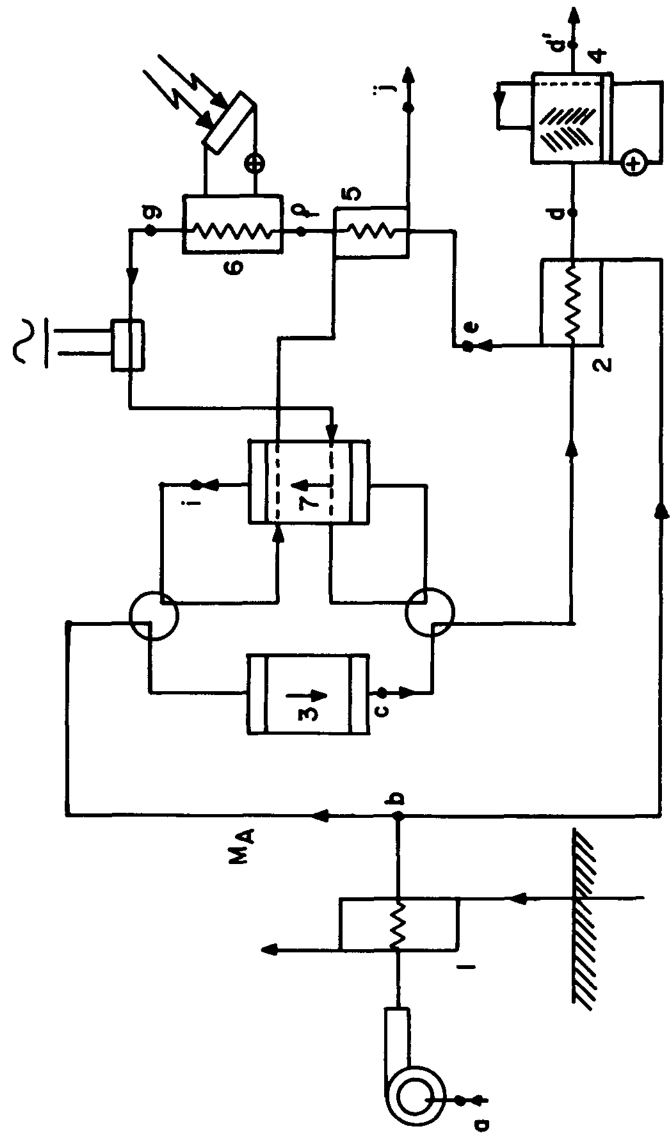

Figure1: FLOW DIAGRAM.

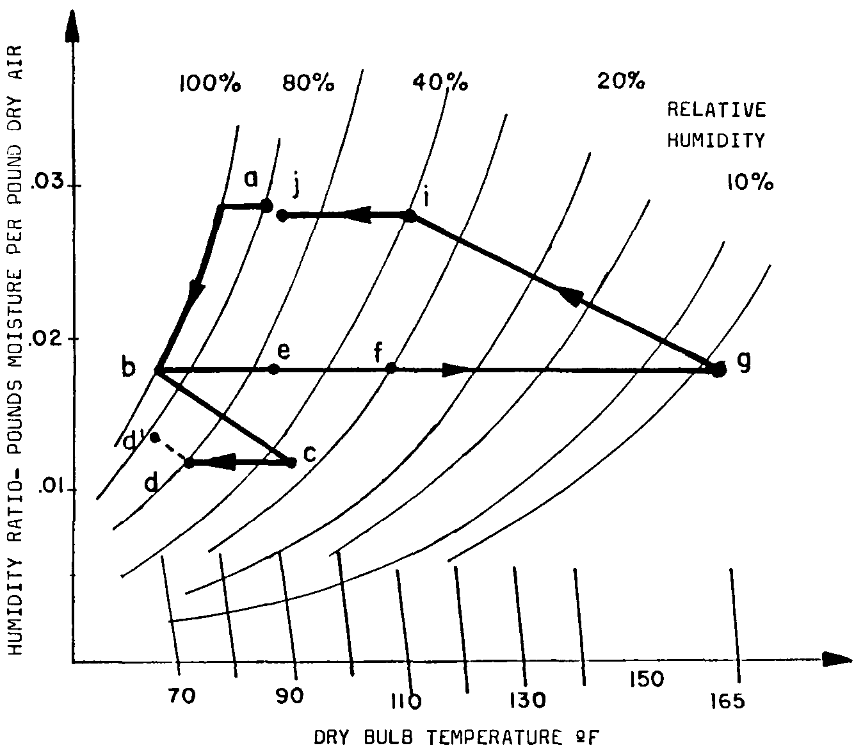

Figure 2: PROCESS LINES FOR THE AIR DESSICATION AND COOLING CYCLE

THE EFFECTS OF AIR MOVEMENT CONTROL ON SOLAR BUILDING PERFORMANCE

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EXTENDED ABSTRACT

Two factors dramatically effect the quality of the environment in a primarily passively heated, solar building: a lack of high quality precise data which would supply accurate design parameters, and second, certain discrepancies between natural heating and cooling phenomena and human comfort. Both of these problems can be resolved with an effective air motion control system.

Even with ideal performance parameters available other restraints such as site requirements, owners' wishes, and construction costs may restrict the implementation of the optimum design. Such concessions will naturally effect the thermal performance of the completed structure resulting in stale air, hot spots, drafts, etc.

Besides basic design aesthetics, human comfort also can restrict optimum energy design. Such factors as localized direct gain overheating and temperature stratification in a building may not be acceptable for reasons of comfort; a dining table by a south facing window, a bedroom on the second floor.

By imitating a natural convective flow, matching rate of air flow with changes in temperature, effective use can be made of naturally heated or cooled air. This paper will examine the effectiveness of a sophisticated air motion control strategy by examining some of the following points and comparing theoretical assumption to actual performance data:

- Why a variable flow rate results in an efficient use of naturally generated heat or naturally cooled air.

- How a naturally heated space can be effectively thermally balanced throughout the course of the day.

- Why controlled transfer may be the only way to efficiently marry the solar energy input with other sources such as wood stoves, ambient air heat pumps, peak heat traps, and conventional heating and cooling systems.

- Why the control energy must be small compared to the energy controlled or transformed or be small compared to the amount of auxiliary energy used if no control were available.

- How a sophisticated and expandable air motion control system can help to resolve complex design problems while providing an effective means for tuning a primarily passively heated building for optimum performance.

AMMONIATED SALT HEAT PUMP

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ABSTRACT

Laboratory investigations and subscale tests of liquid and solid ammoniate salt systems carried out under contract to the U.S. Department of Energy are used to study the system economics and obtains design data for a residential sized solar energy storage system for heating and cooling. The work was scoped to obtain engineering data that is needed to implement this concept as a integral part of solar energy systems.

Thermal analyzer experimental data and published heat of reaction and rate data are compared and used to establish the reactor size and heat exchanger area needed to meet the system requirements for the hetrogeneous ammoniation of $Mg\,Cl_2$, $Ca\,Cl_2$ and $NH_4\,Cl$. These salts were investigated between the following products:

$Mg\,Cl_2 \cdot 6\,NH_3 - Mg\,Cl_2 \cdot 2\,NH_3$
$Mn\,Cl_2 \cdot 6\,NH_3 - Mn\,Cl_2 \cdot 2\,NH_3$
$Ca\,Cl_2 \cdot 8\,NH_3 - Ca\,Cl_2 \cdot 4\,NH_3$
$Ca\,Cl_2 \cdot 4\,NH_3 - Ca\,Cl_2 \cdot 2\,NH_3$
$NH_4\,Cl \cdot 3\,NH_3 - NH_4\,Cl$

The results of an experimental program carried out at Colorado State University on the effect of gas flow through a fixed bed on heat transfer between the bed and heat transfer tubes was used to determine the surface area needed. Internal ammonia recirculation incorporated in fixed bed subsystem reactors determined this feature had no effect on heat transfer.

Data on liquid carrier fluid systems and liquid ammoniated salts systems shows the impact of enhanced heat transfer coefficients. This decreases the overall cost by reducing the heat exchanger area and reactor volume necessary to meet the requirements.

A mathematical model of coupled reactor systems, which includes transient startup and shutdown conditions, has been formulated and solved by computer for the macro system. It simulates the operation and is used to test design conditions.

The results of laboratory tests to determine the physical properties of the salt systems including: bulk density, thermoconductivity, bed porosity and volume change during reaction are also used to determine the salt systems selected for study.

An economic analysis of the coupled reactors used as an energy storage system for solar heating and cooling shows that the heat transfer surface needed in fixed bed reactors is the major cost. Experimental work done in a subscale system verified these preliminary results.

A SOLAR POWERED Li-Br ABSORPTION AIR CONDITIONING SYSTEM

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ABSTRACT

The main purpose of the present paper is to introduce the Lithuim Bromide (Li-Br) absorption dual cycle avoiding the use of wet cooling tower. This cycle actually consists of two cycles; the high and low temperature level cycles. Each cycle, which is similar to the conventional cycle, consists of generator, condenser, absorber and evaporator. The main driving heat energy supply to the generator of the high temperature level cycle (H.T.L.C.) may be tapped from solar energy. The H.T.L.C. absorber rejects its heat to the atmosphere. And this is the main advantage of using such cycle. The cooling effect of the system will be through the low temperature level cycle (L.T.L.C.) evaporator. At this stage, the heat exchange between the system, as a whole, and the environment has been accomplished.

The interchange of heat between H.T.L.C. and L.T.L.C. occurs as follows. The H.T.L.C. condenser supplies heat energy to the L.T.L.C. generator. The temperature level of this heat supply should be high enough to generate the water vapour in the L.T.L.C. The H.T.L.C. evaporator will serve as a heat sink for both absorber and condenser of L.T.L.C. Also, at this stage, the heat exchange between the two cycles has been completed. The heat balance requires for both H.T.L.C. and L.T.L.C. that the sum of the heat supplied to the generator and the cooling effect by the evaporator must equals to the

heat rejected by condenser and absorber. And, in the same time and for best design the H.T.L.C. condenser heat just equal to the heat required for L.T.L.C.generator. Also, the cooling effect of the H.T.L.C. must equal to the sum of the heat rejected by the L.T.L.C. of absorber and condenser With these in mind and to satisfy the physical constrains of the working pair, Li-Br and water, (crystallization and water icing) a very tedious calculations may be needed to construct the dual cycle.

The present study introduces a computer programme which was developed to construct and evaluate the cycle satisfying the above mentioned constrains. The characteristics of the system, accordingly, may be studied at different environmental conditions. These affecting environmental conditions are the H.T.L.C. generator, atmospheric and L.T.L.C. evaporator temperatures.

The dual system is very much appropriate for places where the solar energy is available and where the water is rare and consequently the cooling tower may be eliminated.

SESSION 4C

RURAL SOLAR APPLICATIONS

ON SOLAR GRAIN DRYING

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EXTENDED ABSTRACT

Recently most efforts on applying solar energy to grain drying has been directed to modifying the existing systems by using solar collectors installed on both sides of the grain drying bins. In the present study, a prototype grain (peanut) dryer is discussed and the heat and mass transfer analysis associated with solar drying is presented. The unique feature of the present system is that the dryer unit itself serves partly as a solar collector. The system consists of a gothic shaped chamber made of tedler coated clear corrugated fiberglass and has dimensions 7.7m wide, 4.0m high and 8.5m long. The clear fiberglass has radiation transmission properties that produces greenhouse effects inside the chamber which is situated on a flat concrete slab and block wall foundation. Inside the chamber, there is one cylindrical dryer unit 2.2m in diameter, 4.6m long and has a capacity to hold approximately 3 to 4 tons of peanuts. During the drying, the drum rotates slowly (i.e., about two revolutions per hour) in order to maintain uniform drying of the peanuts. The cylindrical surface of the dryer is perforated (i.e., about 50% perforation) to permit the hot air from the chamber to enter the drum, flow through the peanuts inside the drum and then either to be exhausted into the outside atmosphere or recirculated through the chamber. The black surface of the drums also acts partly as a solar collector, because it is heated by the absorption of solar radiation incident upon it and dissipates the heat both into the air in the chamber and to the peanuts.

By utilizing the present analysis, a parametric survey is made to examine the effects of various system input parameters such as the solar radiation intensity, the air flow rate through the chamber, the temperature and humidity of outside air and the absorptivity of floor surface to solar radiation on the heating of air inside the chamber and the drying time.

SOLAR ENERGY ASSISTED FLUIDIZED BED FRUIT DRYING

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EXTENDED ABSTRACT

Fluidized beds are excellent media for heat and mass exchanging processes. There are various reported studies on this subject. The so-mentioned benefits offered by fluidized beds apply to a great variety of fields. One of the applications which gains more and more interest is the fruit drying process using non-conventional energy resources. In this process, fruits are dried in a vertical vessel through which heated air is passed in a controlled manner. Due to the agitation and mignation of the fruit particles, the heat and mass transfer coefficients among the particles and the particle-gas interface increases appreciably [1,2]. Yet the bed characteristics depend on many parameters which may vary so much that no any simple theory for design could be unified. The governing equations are still based upon intensive experimental data in the related fields and of special interest.

Today's energy crisis dictates for all kinds of processes that the energy consumption and demand should be kept at a minimum level for an optimum operation regime. Naturally, this argument also holds for fruit drying. It is a very old tradition of using solar energy in this field. Yet, the so-called "open-air fruit drying" usually does not lead to optimum and satisfactory results. Meterological effects, the relatively long drying periods, lack of an effective and cheap means of process control generally cancel out the benefits presented by the sun. In addition, the basic heat and mass transfer phenomena over the whole range of drying process is still an important subject of research [3]. Thus, the second focus of interest in fruit drying is the use and control of solar energy for a satisfactory drying regime. Various new proposals have already being made and applied to eliminate the above mentioned drawbacks of "open-air drying".

This research tries to combine and couple the benefits of fluidized beds and the solar energy for fruit drying as a new design alternative. To achieve this goal two basic research studies were done:

1.) A finite-element analysis of the behavior of fluidized beds: A general computer program was developed to simulate and predict the performance characteristics [4]. This enabled analysis of several design alternatives for the fluidized bed itself in an interactive mode.

2.) Analysis of applicability and usefulness of solar energy as a driving source for such fluidized beds: The main driving force in the fluidized bed is the upward moving hot air. The applicability of solar energy at different modes of this process was anlayzed and concluded that solar energy can be incorporated at different phase, such as air heating, bed heating and creating an upward flow of air.

This analyzes both in theory and experience the proposal of a solar energy assisted fluidized bed fruit drying process. The basic relevant theory is given and various design alternatives are discussed.

The results have shown that a feasible design can be realized for certain applications under favorable operating conditions.

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A SOLAR ENERGY SYSTEM FOR THE THIRD WORLD

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EXTENDED ABSTRACT

In April, 1975, the Governing Council of the United Nations Environment Programme (UNEP) issued a decision which addressed the problem of providing energy to remote villages in the developing world. The decision expressed the belief that existing technology could be used to harness renewable resources such as solar and wind energy, and the energy which can be derived from plant and animal matter as inputs to an energy system which could provide power to such villages. As a result of that decision, Oklahoma State University was chosen to develop plans for a Rural Energy Center (REC), to be installed in Sri Lanka, which might be a model for future centers in Asian villages. Construction of the system is now underway, and it is expected to be in full operation by Spring 1980. When completed, the REC in Sri Lanka will represent the first effort to harness renewable energy resources in a manner which will benefit an entire village in a developing country.

The Sri Lanka REC utilizes a multiplicity of renewable energy resources, energy storage mechanisms, and energy conversion schemes to provide reliable energy to a remote village in that country. In electrical terms, the system has a rating of at least 50 kW, and it is designed to operate at that power level for approximately six hours per day. A schematic of the Sri Lanka REC isshown in Figure 1.

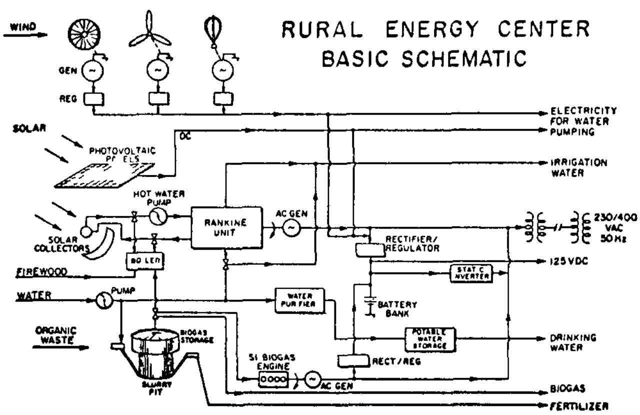

Figure 1. Rural Energy Center Basic Schematic

Inputs to the system include solar radiation, wind energy, firewood, water, and organic wastes. Four Dunlite 2000 windmills are used to convert wind energy into electrical energy which can be used for a wide range of applications, including battery charging and water pumping. A 2 kW photovoltaic panel and an Omnium-G solar thermal unit with a 7.5 kva rating will act as a compliment to the wind energy components of the system. The electrical output of the solar and wind energy subsystems can be connected to a storage system whose output will be available when solar and wind resources are not directly available. Organic wastes, consisting primarily of cow dung, are mixed with water and inserted into a biogas system, which employs an anaerobic fermentation process to convert this waste material into biogas (60% methane and 40% carbon dioxide, with minor trace gases and water vapor). The biogas unit was designed and constructed by the Khadi and Village Industries Commission of Bombay, India, and it is capable of producing 85 m^3 of gas per day. The gas is stored in a reservoir which covers the unit, and it can be used directly for cooking or heating requirements, or injected into a spark ignition engine developed by Onan, for the production of mechanical or electrical power.

The system described above can be economically competitive with the two conventional schemes of supplying electricity to remote villages in developing countries - autogeneration and power grid extension - when it is mass produced. When its performance has been documented, it is anticipated that the REC in Sri Lanka will offer hope for a better life for millions of people in the developing world who are presently unable to benefit from the advantages offered by twentieth century technology.

SOLAR RAISIN DRYING IN IZMIR

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EXTENDED ABSTRACT

In Turkey, usually, drying of fruits and vegetables is done in open air, Open air drying is cheap, but it depends on the regional meteorological conditions and not always clean enough. International standards demand a certain quality of dried fruits and vegetables. In order to be able to be competitive in the international market some of the firms in Turkey has began to dry their fruits and vegetables in dryers. 1973 we started to compair open air drying of raisin with the drying of raisin in the plate dryer[+] The idea to design a solar dryer came with oil crisis in 1973 in order to reduce fuel oil consumption in Turkey. In our Institute we begun with Altenkirch's solar drying house, and the second work is the raisin dryer which is developed entirely in our Institute as a Ph-Thesis[++].

In the present work the experimental results of open air raisin-drying from 1973 and the results of raisin drying in a solar dryer from 1978 will be given.

OPEN AIR DRYING

Experimental invastigation in order to compare the results of open air drying with the results of the raisin drying in common dryers has began in August 1973. Experiments has been carried out between 20 August 1973 and 10 September 1973 in the research laboratories of the Faculty of Agriculture. 80 kg fresh raisin has been treated about 10 second with 4 - 5 % Potasium Carbonate solution with 0.5 % oil content. Afterwards they have been put on to a concrete bottom. The moisture content, sugar content, acide content and colour of dried raisin have been determined. In Table 1 the starting values and the results of experiments are giv

+ M.S. Thesis 1974, University Ege
++ The research work has been carried out by Dr.A.Çetin Gürses and supported by Turkish Scientific and Technical Research Council.

In Table 1 the results of three different experiment are represented. From the data given in Table 1 it is obvious that the drying process in at the beginning relatively intensive in order to slow down with time. Within the first four days the moisture content decreases about four times more than in the following six days. This results more and less is usual in open air drying.

For the drying periode 22.8.1973-31.8.1973 the total amount of dried raisin is less than it should be. This is the lost which is carried out by birds or by someone else. Otherwise the material balance would be wrong.

SOLAR DRYER

The raisin dryer presented here consists mainly one air heater, six drying sieve plates and one chimney. Its overall dimensions are: 1800 mm length x 2200 mm height x 1200 mm width, Fig.1. The single glazed air collector facing to the south has black painted wings which lead the heated air into the drying room. Six drying plates are placed in the drying room. Because of the inclenation of the air collector the cross section area of the drying plates decrases from the bottom to the top of the dryer. In the north the chimney of the dryer is placed which is painted black. East and west side walls are made of fiber glass embeded in molten plastics mass.

Atmospheric air enters into the air collector at the bottom. It is heated in the air collector and leaded through the wings into the drying room. In the drying room the heated air comes into contact with the raisin to be dried. Afterwards it enters into the chimney and leaves the dryer at the top of the chimney.

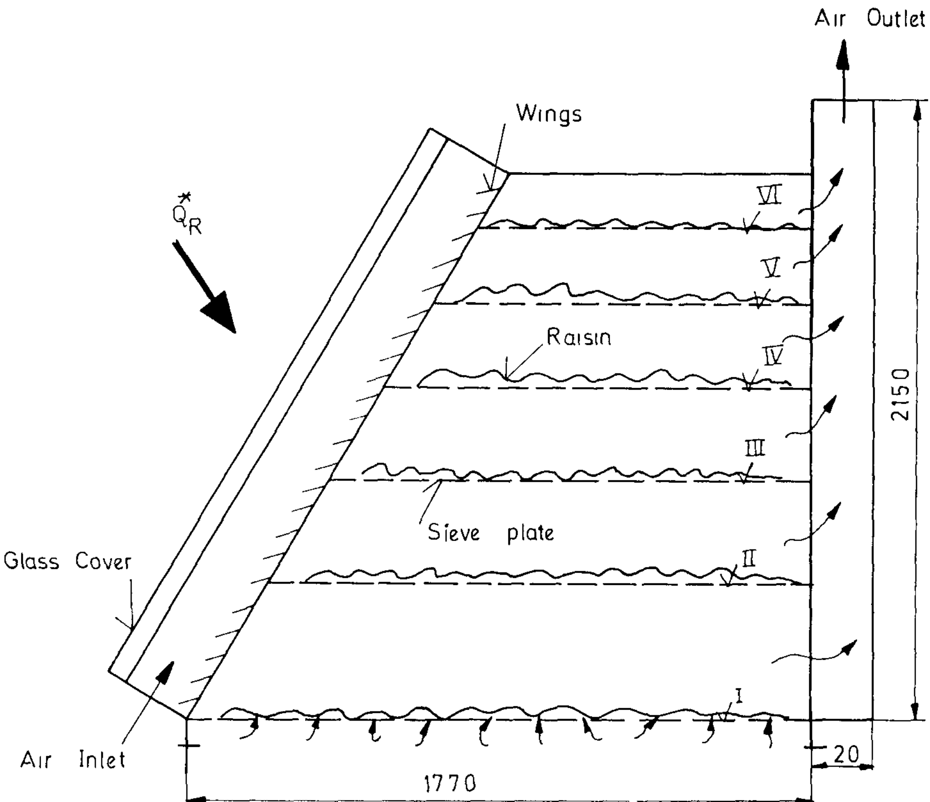

Fig 1. Raisin - Dryer, schematically

PASSIVE SOLAR ENERGY EFFECTS ON EGG PRODUCTION AND FEED EFFICIENCY

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EXTENDED ABSTRACT

INTRODUCTION

Since the early days of the Greeks there has been evidence that hens lay fewer eggs when the cold weather comes on [1]. The U.S. Department of Agriculture (USDA) has produced curves to show how egg production and grain efficiencies behave with various housing temperatures [2]. They show that as the temperature goes above or below a range of about 50-75°F both egg production and feed efficiency drop off considerably. This paper shows that the USDA curves prove to be accurate in predicting egg production even for a small number of hens. Egg production and feed consumption of the hens in the solar hen house are compared to those of non solar installations of a few hundred hens and several thousand hens [3] in typical commercial egg production facilities.

First Experiment The solar hen house is shown in Fig. 1; the overall size is 8 feet by 8 feet with a 45 degree double-glass south facing surface. No electricity, gas or oil is used. The ventilation is a wind driven ventilator with a manually controlled damper; the footing is insulated with 2 inches of polystyrene and is 2 feet deep; and the storage medium is 2295 pounds of water stored in 55 gallon drums.

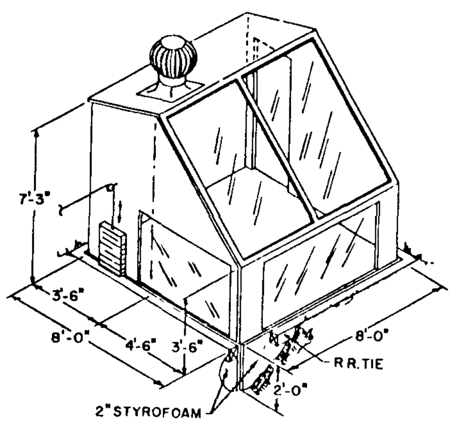

Fig. 1 Solar Hen House.

*Work performed privately at home.

The hen house is solidly built and well insulated; all the glass surfaces are double glass. The 10 hens are Rhode Island Reds that were barn raised for 30 weeks and then moved to the solar hen house on November 1 1978.

During the first twenty-week test the actual total number of eggs (1008) was within 6 percent of the predicted number (1067). The reason for the higher number of predicted eggs might have been that the predicted number was based on temperatures read at eye level whereas the hen's environment was mostly on the floor where the temperature was about 4 degrees lower.

The predicted number of eggs for the same period, based on barn housing with no external heat, was determined. The barn housing data is based on a 28 year record of local outside mean temperatures [4]. The accumulative number of eggs from hens raised in the barn climate for the same twenty-week period is 853. The mean temperature increase of 22°F provided by the solar hen house showed an increase in egg production of 155 eggs for the test period. Actual and predicted grain consumption were also compared for this period. Only 418 pounds of feed were used in the warmer solar environment as compared to 498 pounds which would have been used in the nonheated barn housing according to predictions based on USDA [2] curves.

Second Experiment The second twenty-week test showed similar results even as the weather got warmer. The hens were 50 weeks old at the beginning of this second experiment and 69 weeks old at the end. Their production declines somewhat during this time but remains higher than that of the commercial egg production facility with which it was compared [3]. The egg weight was 19% higher with an average of 2.49 ounces per egg versus 2.10 ounces per egg for the commercial facility. The feed conversion ratio for the commercial facility was better than that of the solar hen house if figured by the number of eggs. However, if the weight of the eggs is figured, the solar hen house provided better feed efficiencies.

The second twenty-week experiment showed that the passive solar hen house provided a climate where the hens produced 88 more eggs (9%) using 42 pounds less grain than similar results predicted with USDA data. This happened as the weather warmed up considerably; the final week had an average inside temperature of 85.4°F. Daytime shading from the sun was attempted with mixed results. This is described in the final paper along with operating and construction costs.

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LATENT-HEAT SOLAR COLLECTION AND STORAGE: APPLICATION TO AGRICULTURE

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EXTENDED ABSTRACT

INTRODUCTION

The experimental results presented here have been obtained on a solar chicken breeder built in Andahuaylas, in the peruvian Sierra (altitude ≃ 3000 m, latitude ≃ 13°S) [1]. The installation is divided into two parts, a patio built according to the usual scheme of a peruvian adobe house, and a communicating solar heated enclosure. The latter is made of thick adobe walls, and its roof is a solar collection-storage system consisting of two tanks of paraffin-wax located below gloss panes.

The present experimental results have been obtained after having improved a first version of the breeder [1] and they are compared to the first ones.

This communication also includes a comparison of the behaviour of the system with and without chickens in it.

We study the variables that characterized the fitness of the system to its purpose : breeding young chickens that must be kept in a given range of temperatures, with the air being regularly renewed. These variables are the enclosure and patio minimum and maximum temperatures.

SHORT-RANGE COVARIATION OF THE VARIABLES

In this first paragraph the short-range correlations of the minimum and maximum inside temperatures with the external temperatures as well as with the global insolation and wind velocity are analyzed on the basis of the measurements made. These measurements include different periods of the year and different conditions of night insulation, in the absence of chickens.

The main results are as follows :
* The daily variation of the enclosure minimum temperature, during any period of the year, depends very strongly on the global insolation of the previous day, more loosely on the insolation of the one or two preceding days, and very little on the external temperatures.

* The daily variation of the enclosure maximum temperature depends very strongly on the wind velocity and global insolation of the very same day and very little on the behaviour of the system during the previous days.
* The only effect of not insulating the roof at night is to lower the mean-value of the inside minimum temperature. The covariations of the variables are similar to the ones obtained in the insulated case.

LONG-RANGE MEAN VARIATION OF THE VARIABLES

In this second paragraph, the long-range mean covariations of the same variables are studied with the help of mean-values and standard deviations of the variables that are estimated for various periods of the year, each one consisting of several weeks.

* The enclosure minimum temperature mean-value is shown to oscillate very little during the whole year and to be strongly correlated to the global insolation mean-value. It is very loosely correlated to the outside temperature mean-value and the yearly variations of its standard deviation depends on the yearly variations of the global insolation standard deviation only.
* The mean-value and standard deviation of the enclosure maximum temperature variations follow the mean-value and standard deviation of the outside maximum temperature variations.
* By comparing these results to the ones obtained in the first step [1] of our experimentation, the combined effect of better insulation and air renewal is shown to be a higher and more stable enclosure temperature.

EXPERIMENTAL RESULTS IN THE PRESENCE OF CHICKENS

In this paragraph, the same variables are studied with chickens being brought up in the breeder. The results are compared to the previous ones, and the behaviour of the chickens in our solar breeder is compared to their behaviour in a conventional breeder.

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DEVELOPING AN ECONOMICALLY FEASIBLE SOLAR BROODING SYSTEM FOR BROILER PRODUCTION

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EXTENDED ABSTRACT

INTRODUCTION

Since 1973, engineers at the Delaware Agricultural Experiment Station have been working with the Delmarva Poultry Industry to develop a computer simulation of on-farm broiler production. Originally, the purpose of the simulation model was to demonstrate the economic feasibility of energy conserving techniques such as limited area brooding, added insulation and ventilation system operation. It is estimated that the combined effect of limited area brooding and added insulation (14 cm of fiberglass) has resulted in a savings of 12 million liters of liquified petroleum (LP) gas per year for Delmarva growers when compared to a typical 1973 house (5.4 cm) with whole house brooding. With respect to the operation of the ventilation system, over-ventilation by 1.4 L/min/bird will increase fuel consumption by 50%.

As the cost of LP gas has continued to rise, there has been an increasing interest in the development of an alternative energy source for brooding chicks. The computer simulation that is being developed provides a tool for evaluating the economic feasibility of solar brooding systems. Two important factors must be considered when designing a brooding system. First, the system must provide brooding temperatures of 29°C to 32°C during the first week. Second, the supplemental energy required for brooding declines very rapidly, and after the broilers reach four to five weeks of age, almost no supplemental heat energy is required.

Economic Considerations

The computer simulation indicates that a solar brooding system tailored to a specific broiler operation can be economically feasible. Based on the following conditions, a) 20 year life (except film surface), b) current cost of LP gas at 12 cents per liter, c) 15% inflation rate for LP gas (typical of last 5 years), d) 9% interest on mortgage equal to 80% of first cost, e) 5.5% return on down payment, f) 1% of first cost for insurance, g) 2.25% of first cost for maintenance, and h) ventilation for moisture removal during the colder months. In a broiler house with 7.62 cm of fiberglass, 1/3 house brooding (an energy conservation practice widely used on Delmarva) and 20,000 broilers, the installation of a 74-square meter collector and 3-gigajoules storage will reduce the total cost (ownership plus energy) by $2338. If the above house and solar system were used for a whole house or non-restricted brooding operation, the model projects that the solar system would reduce the total cost by $15,354. However, in terms of total cost, the 1/3 house brooding operation would be preferred.

Based on the above conditions, the expenditures for the solar brooding system can be obtained. The first cost of the collector cannot exceed $27 per square meter. Assuming energy storage in water, the storage unit cannot exceed $35 per cubic meter. It is expected that part of the $2338 reduction in total cost would be used to buy accessories and pay for additional electrical energy to operate the system. The computer program is now being modified to include these costs.

System Design

The design criteria of 32°C brooding temperatures and the cost constraint of $27 per square meter for the collector indicated a low-cost medium-temperature concentrating collector was needed. After considering costs, maintenance and ease of construction, a cylindrical, fixed-mirror, east-west oriented, ground-level-constructed collector was selected.

The basic design concept for the collector is to use low-cost aluminized mylar film to form the reflective surface and periodically replace the surface to maintain collector efficiency. The low-cost reflective surface is formed by draping aluminized mylar over a frame supporting two parallel rails, enclosing the outer area with polyethylene film and applying a vacuum of 0.5 to 1.3 cm of water. The resulting surface has a circular cross-section with a paraxial focus at ½ the radius of curvature. The rails are located such that the arc of the reflective surface subtends an angle of 80° and the perpendicular bisector of the arc is 45° from the vertical. The frame is constructed from readily available electrical EMT conduit and easily fabricated piece-parts. The rails are presently used in greenhouses and are designed for the easy replacement of plastic film.

The absorber tube consists of two concentric tubes with three radially oriented fins attached to the outer tube. The length and spacing of the fins allow for small errors in absorber orientation without substantial losses of incident solar energy. A highly absorbtive, non-selective coating and glass glazing are used on the absorber for minimum cost and ease of construction. Water is used for the heat collecting fluid as well as the heat storage medium.

The water storage tank is constructed from preformed, corrugated sheet-steel ring segments presently used in grain storage tanks. A high quality long-life liner is used to seal the tank. To increase collector efficiency heat stratification is maintained in the storage tank.

Based on 1979 costs, the retail price for readily available collector materials in the present design totals $25 per square meter for the collector and $30 per cubic meter for water storage based on a collector system of 92 square meters. Costs of the basic components of the collector on a per square meter basis are $9.70 for the frame, $8.40 for the absorber tube, $2.80 for the plastic, and $4.10 for the controls and fan. These costs are for materials only and do not include labor or profit for the construction contractor. The design is continually being modified to reduce the material costs so that the total cost including labor, will approach the allowable cost constraint.

The desired system operating temperatures are $38^{\circ}C$ inlet temperature and $87^{\circ}C$ outlet temperature. The collector efficiency ranges from 40% to 60% at solar noon for a clear day based on the effective area of the collector. The energy required for maintaining the vacuum for a 100 square meter collector is less than 40 watts.

INDIAN ENERGY SOURCES IN 1980's

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ABSTRACT

The Indian oil and coal resources are moderate, but hydroelectric resources are quite rich and comparatively inexpensive. Hydroelectricity today accounts for 43.5% of the installed capacity of 16,000 MW. By 2001, it is still expected to account for 37% of the 16,2000 anticipated capacity. Availability of electricity is crucial for economic growth, yet the past performance has been poor. Immediate and concentrated efforts are required for the development of hydroelectricity if our electrid power needs are to be adequately met. The captial intensive nature of hydroprojects and their long gestation periods have acted as impediments in rapid exploitation of hydroelectric resources in the country. There is scope for minimizing the costs and gestation period by intorducing modern management and construction techniques. A soft path approach to the energy crisis is advocated as against the hard path, which is characterized by growing reliance on huge centralized power systems and grids depending on fossil fuels or increasingly on nuclear energy. The soft path, curbs and reduces the nation's energy appetite by means of technical fixes that can cut energy waste in half. Alternative sources of power such as solar and wind energy, biomass conversion and the utilization of industrial waste heat to produce electricity are discussed. Case studies are presented.

DESIGN, DEVELOPMENT AND TESTING OF 2 TONS/DAY SOLAR ENERGY OPERATED PADDY PARBOILING AND DRYING UNIT FOR RURAL AREAS

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EXTENDED ABSTRACT

Certain paddy varieties, when milled in raw state, are subjected to considerable breakage due to their inherent poor milling qualities and thus give low head yields. This head yield can be increased by subjecting the paddy to a premilling treatment known as parboiling of paddy.

Parboiling of paddy is a hydrothermic treatment to the raw paddy followed by drying to bring the moisture content back to an optimal level of milling or storage. The basic requirements of the parboiling are soaking of paddy to increase the moisture content to about 30 percent steaming to gelatinize the paddy starch and drying paddy to bring the moisture content back to an optimum milling level. In the method developed by Rice Process Engineering Centre, I.I.T. Kharagpur, W.B. India for paddy parboiling (1), the process of steaming is eliminated by increasing the soaking time a little and thus producing rice of comparable quality in milling, cooking and nutritive values with less cost as compared to the steam parboiled rice.

The paddy parboiling is carried out for more than 200 days in a year. It has been estimated that one tonne of paddy requires 2,56,000 Kcal of heat for complete parboiling process including drying (parboiling, 1,20,000 and drying of parboiled paddy, 1,36,000 Kcal). With the present crisis of different fuels for producing thermal energy, a saving of more than Rs.25,000 (U.S. $3,000) per year can be made by the use of solar energy which is freely available and is in abundance in this country except during the rainy season.

The present study was a sort of feasible study with the intension of using this source of energy in small scale rice mills or farms. The main objective of this study was to develop the most effective parboiling system for parboiling and drying of parboiled paddy and to compare this process economically with conventional systems using other sources of fuel.

No research work has been reported on parboiling of paddy using solar energy, but some work is available on drying of parboiled paddy particularly at Annamalai University, India (2) under deep bed drying method which suffers with number of draw backs. A little work is done for drying raw paddy at IARI, Delhi, India (3).

On the basis of review made and tests conducted on three types of concentrators namesly flat plate collector with side reflectors, parbolic cylindrical concentrator and multiple mirror concentrator with central absorber, A parabolic cylindrical concentrator was used for parboiling of paddy and a flat plate air heater of conventional design with one glass cover was used for drying of parboiled paddy.

A pilot plant of about 100kg per day capacity for parboiling and drying of parboiled paddy was designed and tested to judge the feasibility. The parboiling unit consisted of a parabolic cylindrical concentrator of 3.6 m long and 1.86 wide with a focal length of 46 cm and four well insulated brick masonary parboiling tanks. The hot water heated by concentrator to the required temperature was directed to parboiling tanks in which raw paddy already filled. The paddy and water mixture was allowed to remain for 3-4 hours for soaking purpose. It took 3.25 hours for IR-8 and 3.50 hours for Jaya in a well insulated parboiling tank. The overall paddy parboiling system efficiency was about 36 percent.

The drying unit consisted of a recirculatory thin layer batch dryer a flat plate solar air heater, a blower, an auxiallary electrical air heater and air ducts. A flat plate solar collector of conventional design with single glass cover,10.8 m^2 surface area was used as an air heater. This collector was connected to a bamboo drying chamber by means of a blower and air duct. The material of the air heater absorber plate selected was corrugated G.I. sheet most commonly used in the village houses. The frame work was from wood and the insulation was of coconut fiber supported on the hessian cloth. The drying chamber was made from bamboo splits which are easily available in rice growing areas. The whole drying system was designed with the intention that the roof of a farmer's house or small rice mill shed can be converted as air heater. The orientation of the air heater was kept as south facing with an inclination of about 20 with the horizontal to facilitate the entry into the shed. A 3 mm thick glass cover was used as it was cheap easily available and more effective than plastic cover.

The soaked parboiled paddy from parboiling unit was placed in the drying chamber. Parboiled paddy was dried at an air temperature of 60°C $\pm$ 5°C and air flow rate of 15.25 m^3/minute. The average drying rate in percent moisture per hour was 5.0 percent, with the total and head yield to be 75 and 69.02 percent for IR-8 variety. The total drying time was 8 hrs. An average overall drying efficiency of 67 percent was attained for the system.

Paddy samples for moisture content, milling properties and cooking qualities were analysed in the grading laboratory by using the standard techniques. The milling qualities of hot soaked paddy were almost similar to that of parboiled paddy by conventional method.

Cooking qualities of hot soaked parboiled rice were intermediate between raw and completely parboiled rice.

To match a mini-rice mill of 2 tonnes/day capacity, design and layout of a parboiling and drying system based on the results of investigations is proposed. The economics of the solar parboiling and drying system per tonne of paddy had been worked out and compared with conventional method.

The capital cost of solar energy based and conventional parboiling plant are approximately Rs.35,000*. The effective reflecting surface area required for solar concentrators is 150 m^2. The costs of parboiling per tonne of paddy are Rs.34.35 for conventional method with coal as fuel and Rs.18.95 for solar energy based method. The capital costs for solar energy based and conventional mechanical dryer units are Rs.32,000 and Rs.40,000 respectively. The costs of drying per tonne of parboiled paddy are Rs.24.70 for mechanical dryer using artificially heated air by direct oil fired burner and Rs.14.41 for mechanical dryer using solar energy heated air. These values show that solar energy operated system is quite economical.

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*1976 price 1 US $ = Rs.8.30 (approximately).

SESSION 4D

COAL TECHNOLOGY II

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APPLICATION OF AVAILABILITY ENGINEERING TO COAL GASIFICATION SYSTEMS

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EXTENDED ABSTRACT

INTRODUCTION

The Erie Mining Company in Hoyt Lakes, Minnesota, and the Department of Energy have studied the feasibility of constructing a demonstration-scale coal gasification system [1]. (See Fig. 1.) The purpose of this paper is to demonstrate that, if a reliability, maintainability, and availability (RMA) study is conducted during the planning and design stages of a system, the design will be improved and costs will be optimized by taking the real cost of system downtime into account.

PROCESS DESCRIPTION AND PROGRAM METHODOLOGY

Erie Mining's taconite pellet drying plant uses 20 MM SCF of natural gas per day, for which a coal-derived, low Btu fuel gas could substitute effectively. The gasifier that Erie Mining is considering is based on Woodall/Duckham technology and can process about 460 tons of either eastern or western coal per day to produce 45 MM SCF of fuel gas with a heating value of 176 Btu (HHV)/SCF (about one-third of the plant's daily fuel requirement). The system can also produce a coal tar and oil product that can be used as a back-up fuel.

This paper describes an RMA study of the Erie Mining gasifier [2]. First, based on a system process flow diagram, the equipment configuration and functional relationships are expressed in terms of availability block diagrams. These easy-to-follow graphical representations are then used to construct an algebraic model.

Second, the availability of the blocks on these diagrams is determined. Each subsystem is considered on the basis of both its reliability, or ability to perform a specified operation, and its maintainability, or the downtime required to perform maintenance on a failed unit. (See Table 1.) After each subsystem availability is obtained, net availability is derived using the algebraic model.

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Table 1. Unit Availability

Units		MTBF (1/λ) (hr)	MTTR (t_F) (hr)	Availability
WD Gasifier	(V-1)	-	-	.9700
Cyclone	(S-1)	8×10^3	36	.9955
Waste Heat Boiler	(E-1)	3.1×10^3	96	.9700
Clear Gas Cooler (per Shell)	(E-2)	1×10^4	75	.9926
Piping		1.33×10^3	48	.9652
Tar Precipitator	(P-1)	1.45×10^3	35	.9764 (Eastern)
		1.12×10^3	34	.9706 (Western)
Top Gas Cooler (per Shell)	(E-3)	1×10^4	75	.9926
Oil Precipitator	(P-2)	1.45×10^3	35	.9764 (Eastern)
		1.12×10^3	34	.9706 (Western)
Venturi Scrubber	(S-2)	5.4×10^3	62	.9887
Stretford Scrubber	(SC-1)	-	-	.9775
Fuel Gas Compressor	(C-2)	3.4×10^3	75	.9784
Fuel Gas Reheat (per Shell)	(E-4)	2×10^4	75	.9963

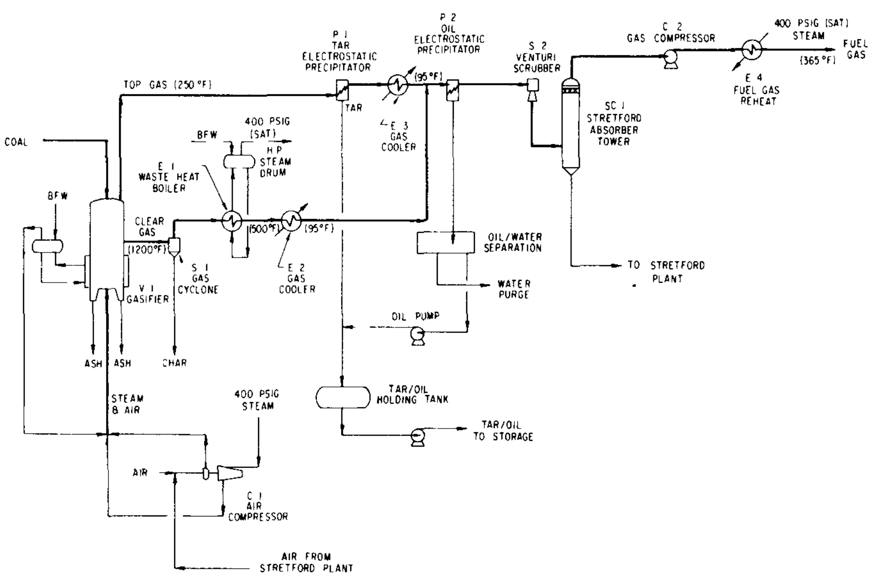

Fig. 1. Erie Mining Process Flow Diagram for Coal Gasification Plant (Adapted from McKee Drawing 4814-Y-002)

The demonstration-scale plant availabilities were used to calculate the annual yield of both the fuel gas and coal tar/oil produced for a scheduled annual operation of 8424 hours. The taconite plant fuel supply goal is the sum of the combined heat released from the combustion of the fuel gas and tar/oil products divided by the taconite plant's annual demand for these fuels (based on 7.4 billion Btu (HHV)/day).

CONCLUSIONS

[This study] indicates that the demonstration-scale plant can meet or exceed a fuel supply goal of 95% if the characteristic equipment availability is as high as the best estimates. Furthermore, this study provides information on the following areas of system operation.

1. Determination of critical and noncritical subsystems.
2. Availability of subsystem equipment.
3. Integrated system availability analysis.
4. Cost advantages for redundant or parallel items of equipment.
5. Costs due to production losses and capital vs. maintenance costs.
6. System sensitivity analysis.
7. Design problem areas resulting from bottlenecking or low availability equipment.

The method presented is simple and flexible enough to be applicable to other subsystems in other plants. The level of effort for this example can be applied quickly and cost effectively to show general trends for consideration.

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WEAR COMPENSATING SEALS FOR HIGH PRESSURE ROTARY PISTON COAL FEEDER

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EXTENDED ABSTRACT

This paper relates generally to seal design in a rotary piston coal feeder used for conveying pulverized coal from the coal hopper to a gasifier wherein the conversion of coal to a high or low Btu gas by gasification occurs.

One of the major problems associated with the operation of coal gasifiers which are operable at pressures up to almost 1500 psig and temperatures in the range of about 1700° to 2500° F has been the transfer of pulverized coal from storage bins at atmospheric pressure into the high pressure gasifiers without suffering extensive system efficiency losses due to the escape of product gas from within the gasifier.

A recently developed coal transfer device which is believed to provide a satisfactory mechanism for efficiently feeding pulverized coal into a gasifier is a rotary piston coal feeder. This work was done at West Virginia University under a contract with the United States Department of Energy. In Phase I of this investigation the feeder was designed for 100 psig discharge pressure at 350°F with a feed capacity of 200 to 1000 pounds per hour. Sealing problems under these conditions must be investigated before feeder design under higher pressures and temperatures can be considered.

The rotary piston feeder has a circular casing with a coal loading opening therein diametrically opposed from a coal discharge and contains a rotatable disoidal rotor having a cylinder in which a reciprocatable piston is disposed. The reciprocation of the piston within the cylinder is provided by a stationary conjugate cam whereby pulverized coal from a coal hopper at atmospheric pressure can be introduced into the cylinder and then discharged therefrom into the high pressure gasifier. The seal arrangement presented in this paper is located between the rotor and the casing about the coal discharge and prevents the high pressure gases from within the gasifier from escaping between these relatively movable parts during operation of the coal feeder. Known seals do not appear to be sufficiently satisfactory since the relative motion between the rotor and the casing together with the presence of the high pressure gases and the abrasive material in the gases render such seals ineffective or subject to excessive wear which would necessitate their replacement at frequent intervals.

The present design utilizes a primary seal in contact with the rotor and a secondary seal supporting the primary seal. The primary seal is continuously urged towards the rotor by springs and the high pressure producer gas acting on it.

Relative merits of using three different materials in such seals are considered and seal wear and gas leakage rates are investigated in each case. For primary seal EPDM rubber (a soft elastomeric), polymide carbon composite (a hard plastic), and Teflon were used, and in all cases the secondary seal was made of EPDM rubber.

The paper also presents in detail the procedures, test equipment and test unit control settings necessary to evaluate such seals under operating pressure conditions.

DESULFURIZATION OF COAL IN BUFFERED SOLUTIONS

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EXTENDED ABSTRACT

INTRODUCTION

There are three basic pretreatments of coal for the reduction of sulfur and ash content: oxygenation, hydrogenation and hydroxide leaching. Previously these reactions were carried out as entirely separate operations. In a program to study the effect of combining any two or more of these reactions the cleaning capabilities of sodium carbonate and sodium bicarbonate were investigated. These results were then compared to sodium hydroxide leaching.

EXPERIMENTAL

The experiments were carried out in 9ml teflon lined stainless steel reaction vessels with 3ml solution and 1gm of coal. The coal used was Lower Clarion, Allegheny vitrinite-pseudo vitrinite with a sulfur content of 7.67%. The coal was ground to -140 to +200 mesh. A stock solution was prepared according to a ratio of sodium in 3ml of solution, to the total sulfur in 1gm of coal (Na/S) equal to 2.0. The experiments were carried out using solutions with concentrations of Na/S=2.0 and Na/S-0.5 at 250^{o}, 215^{o}, 195^{o}, and 140^{o} C.

RESULTS

It was observed that at high temperatures sodium bicarbonate behaved almost exactly like sodium hydroxide. This is assumed to be due to the dissociation, of sodium bicarbonate to carbonic acid and sodium hydroxide (1). As the temperature was decreased to 195 C sodium bicarbonate behaved more like sodium carbonate, and the higher bicarbonate concentration may show the apparent increase on extraction around 190^{o}C that characterizes Na/S=2.0 sodium carbonate extraction. As the temperature decreases from this point both concentrations follow a linear decrease in effectiveness.

The maximum extraction using sodium hydroxide was 77.1% removal of sulfur. The level of extraction was virtually constant for both concentrations fr 250^{o}C to 215^{o}C. At approximately 215^{o}C sidium hydroxide extraction assu a constant decrease in extraction for both concentrations. Both concentrations showed about 25% extraction at 135^{o}C. For Na/S=0.5 sodium hydroxide extraction above 215^{o}C was 61% of the total sulfur content.

Sodium carbonate extraction was not nearly as concentration dependent, showing an average difference in extraction of 5% total sulfur between Na/S=2.0 and Na/S=0.5. However, Na/S=2.0 showed a definite increase in extraction around 195^{o}C.

Four combined systems were also tried at 195°C: 1) NaOH (Na/S=2.0), NaHCO, (Na/S=0.5) giving extraction of 56%; 2) NaOH (Na/S=2.0), Na_2CO_3 (Na/S=0.5) giving extraction of 63%; 3) NaOH (Na/S=2.0), HaHCO (Na/S-0.5), Na CO (Na/S =0.5) giving extraction of 75%; and 4) $NaHCO_3$ (Na/S=0.5), Na_2CO_3 (Na/S=0.5) giving extraction of 80%. The last run listed gave the best results of all the experiments, especially in view of the total sodium concentration (Na/S =1.0).

CONCLUSION

It should be noted that the experiments were carried out in non-stirred batch reactors and were most likely governed as much by diffusion as extent of reaction.

The sodium hydroxide extractions were comparable to the results of other researchers. In comparison to sodium hydroxide, the sodium carbonate-sodium bicarbonate system is much more effective.

Sulfur removal using aqueous carbonates is most probably due to the action of the carbonate compound rather than the bicarbonate compound. Sodium carbonate had been observed as an extremely effective catalyst for steam decomposition in 1926 by Marson and Cobbs (2). The reason for only moderate effectiveness of the carbonate is probably due to limited activity of liquid water. For this reason the formation of more active partially formed water from sodium bicarbonate degradation to sodium carbonate and water helps initiate the carbonate catalysis. The extreme pressure probably retards the sodium bicarbonate degradation and limits the amount of sodium carbonate formed.

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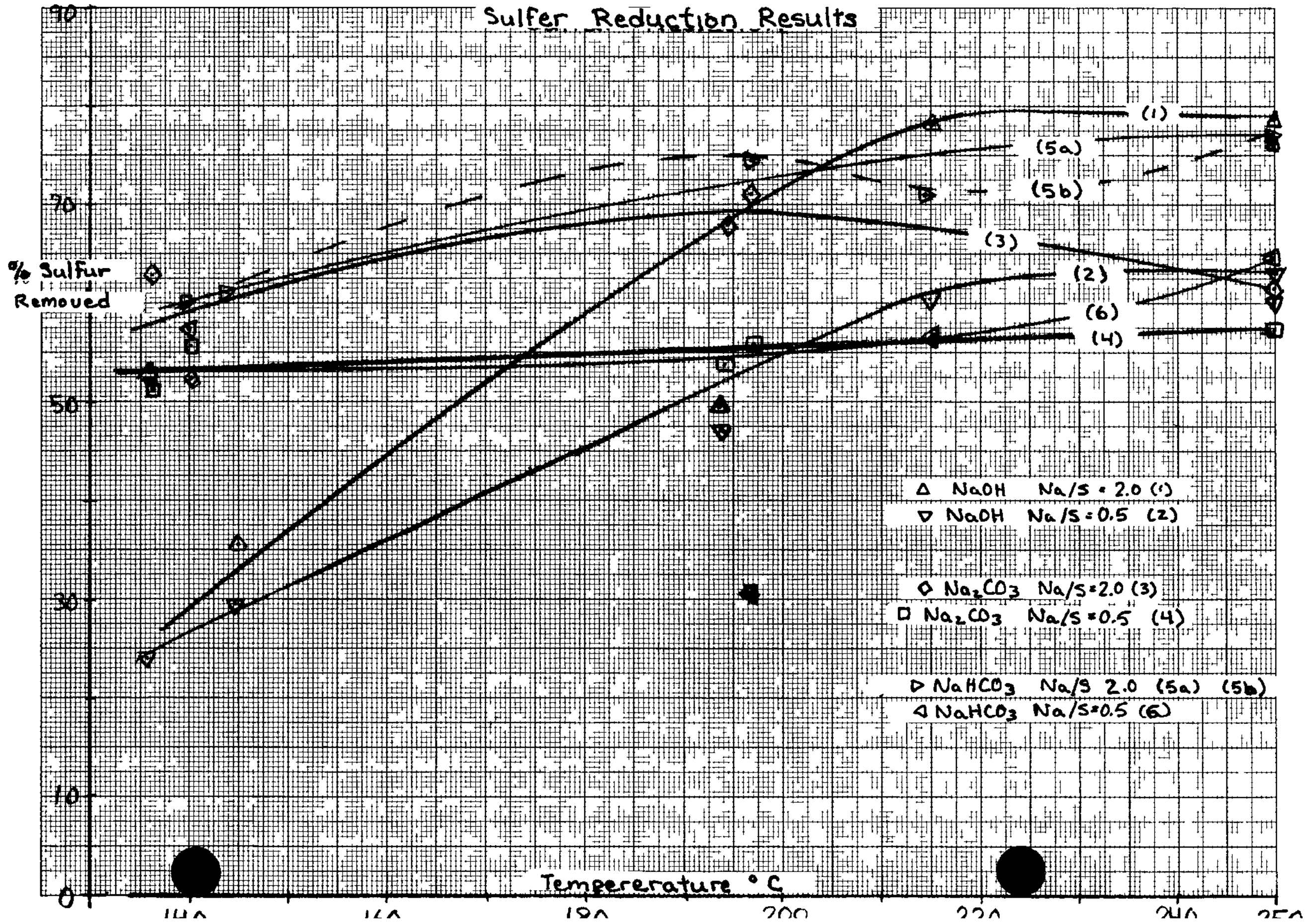
Sulfer Reduction Results
% Sulfur Removed
Temperature °C
0
10
30
50
70
90
140
160
180
200
220
240
250
(1)
(5a)
(5b)
(3)
(2)
(6)
(4)
△ NaOH Na/S = 2.0 (1)
▽ NaOH Na/S = 0.5 (2)
◇ Na₂CO₃ Na/S = 2.0 (3)
□ Na₂CO₃ Na/S = 0.5 (4)
▷ NaHCO₃ Na/S 2.0 (5a) (5b)
◁ NaHCO₃ Na/S = 0.5 (6)

DCI

"FLUID BED HYDROGENATION OF AGGLOMERATING BITUMINOUS COALS"

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ABSTRACT

During 1977, Union Carbide Corporation independently funded an exploratory program to develop techniques for the fluid bed processing of agglomerating coals after the government supported experimental effort to demonstrate the technical feasibility of the Coalcon Hydrocarbonization process for the production of clean boiler fuels was terminated at the end of 1976.

A technique for processing a raw caking coal in a fluidized bed without preoxidation, premixing with char or use of an external hot char recirculation loop, and under the severe conditions of high hydrogen partial pressure and low injection gas/coal ratio was developed. Operation with strongly caking Illinois 6 and Pittsburgh 8 coals, both of high free swelling index, were successfully demonstrated. Using pure, raw Illinois 6 coal, the South Charleston mini-pilot plant hydrogasifier was successfully operated within the material and mechanical energy balance constraints of a commercial-scale reactor. The hydrocarbonizer (capacity: 10-50 lbs. of coal per hour) was operated at 400 psig, with a gas composition of 70-90% H_2, in the temperature range 1000-1100^{o}F.

Fluid-bed operating limits were explored by sequential dynamic testing of the key operating variables. In a typical experiment, the fluidizing velocity would be held constant, and the coal injection velocity reduced by lowering the addition of acceleration gas. As the injection velocity was reduced, the extent of char agglomeration would increase. This would be detected by the increase in the amplitude of the fluctuations recorded across the d.p. taps and also by the lowering fluidized density. A degree of freedom was introduced by use of an attrition jet to effect in situ deagglomeration of the char particles allowing injection gas/coal ratio to be reduced to within the economically viable range. The total energy required to sustain fluid bed operation represents a small fraction (<1%) of the HHV of the raw coal and therefore represents an economically viable as well as technically feasible approach to processing agglomerating coals.

COMBINED GAS-STEAM TURBINE CYCLE USING COAL DERIVED LIQUID FUEL--A VIABLE ALTERNATIVE TO DIRECT COMBUSTION OF COAL?

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EXTENDED ABSTRACT

An alternative to direct coal-combustion for electric power generation is liquefaction of coal prior to combustion in a combined gas-steam turbine plant. For optimization of the overall efficiency of the power plant, individual subsystem efficiencies must be analyzed. However, the prevailing energy analysis based on the First Law of Thermodynamics is insufficient for this purpose and, in fact, can be misleading.

The paper presents a complete thermodynamic analysis (i.e., First and Second Law Analysis) of an 873 MWe combined gas-steam turbine cycle, which utilizes semiclean fuel from the H-Coal process as conceptualized by Westinghouse Corp. and discussed in Energy Conversion Alternatives Study Phase II. The products of combustion pass through heat recovery steam generators (HRSG) before discharge to the atmosphere. The steam generated in the four(4) HRSG's is expanded through a steam turbine with an abbreviated extraction feed-water heating system and with some steam inducted into the cold reheat pipe. In this plant, 65 percent of the station gross power is generated by the four(4) gas turbine-generators and the remainder by the steam turbine-generator, with a power plant efficiency of 52.1 percent and an overall energy efficiency of 38.55 percent. The results of the analysis are presented using "Expanded Sankey" diagrams which show the detailed energy and available energy (essergy) flows in the individual subsystems. This method of presentation is extremely useful in pinpointing, the magnitude and location of true energy losses in a total energy system. Rational methods of evaluating the available energy (essergy) content of the fuel, the working fluid, availability transfer through the subsystem, and individual conversion efficiencies are discussed. The divergence of the results of the analysis based on the two Laws of Thermodynamics is clearly shown and the effects discussed.

For example, while the coal liquefaction subsystem efficiency (η) and effectiveness (ε), based on the First and Second Law Analyses respectively, converge, the η and ε of the individual gas-turbine, HRSG and steam-cycle subsystems diverge considerably and in fact η and ε show opposing results.

For purposes of comparison and evaluation, the liquefier, gas turbine and HRSG has been combined effectively into a "Boiler" unit transferring heat to the bottoming cycle as well as generating electric power. This "combined unit" shows an efficiency (η_B) of 60.7 percent (based on the First Law) and an effectiveness (ε_B) of 43.5 percent (based on the Second Law). Since this "combined unit" includes also the combustor of the gas-turbine (ε_{GT} = 67.7 percent), ε_B necessarily includes the combustion losses, which amounts to 36.4 percent of the liquid-fuel availability (essergy). Comparing this system with the AFB (Atmospheric Fluidized Bed) Boiler (with η_B = 87.9 percent) of the Advanced Steam Cycle System (also discussed in ECAS-Phase II) it is found that the overall energy conversion effectiveness of this system is about 3 percent higher than the said steam cycle with the AFB-Boiler, even though the AFB-Boiler efficiency (η_B = 87.9 percent) is much higher than that of the present system.

These discrepancies are analyzed and discussed. The overall energy conversion effectiveness of the power plant is expressed in terms of its subsystem effectiveness measures (essergetic efficiencies). The efficiency analysis based on the Second Law of Thermodynamics clarifies many misconceptions resulting from the currently prevailing energy analysis and indicate the proper direction for optimization of "energy" utilization. The detailed thermodynamic analysis shows that coal-liquefaction in conjunction with combined cycles is a viable alternative to the direct combustion of coal for power generation.

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ADVANCED SYNFUELS PRODUCTION/POWER SYSTEMS UTILIZING LASER PARTICULATE CONTROL

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EXTENDED ABSTRACT

Direct coal-fired gas turbines, operating as part of a combined cycle are an attractive method of electrical generation utilizing coal. The combined cycle considered herein is a direct-fired turbine utilizing a pressurized fluidized bed combustor (PFBC) or a cyclone combustor and a steam-Rankine cycle where steam is raised in the combustor as well. This system is desirable in the United States due to the domestic availability of coal and the high thermal efficiencies (> 40 percent) that such systems promise. To date the primary impediment to the implementation of such combined cycle systems has been the inability of hot gas cleanup systems to adequately protect turbine blades from erosion and corrosion due to solids entrained in the hot gas exiting the combustor. A possible method of limiting such deleterious effects upon such a capitally intensive piece of equipment as a gas turbine is to fragment entrained particulates below the critical size for impact upon turbine blades.

By the use of intense bursts of laser light, entrained particulates within the combustion product stream may be fragmented to sizes below which turbine blade erosion appears to be no longer a serious problem (< 3μ). Previous system studies of laser fragmentation have centered around pressurized fluidized bed combustors (PFBC's) with multistage cyclones for particulate removal. Two changes to this system have the potential to make it more attractive. Firstly, by using a cyclone combustor, fewer particulates are released from the combustor, which leads directly to a decrease in both laser power and cost requirements. Secondly, steam will be raised to lower the combustion gas stream temperature. As well as generating electricity conventionally through a steam turbine, hydrogen can also be produced by means of high temperature electrolysis.

A pressurized (∿ 10 atm) cyclone combustor exhibits excellent particulate retention. The combustor temperature is--of necessity--above a temperature where ash flows readily. Peak temperatures of 1700-1800K (2600-2800°F) are necessary. Inlet temperature to the laser-particulate fragmentation cavity and gas turbine must be below the ash softening temperature, or about 1150K (1600°F). One method of reducing the combustion gas temperature is by the addition of excess air following the combustor. A more attractive means is to

raise steam in membrane walls in the radiant zone of the plant as well. Laser recirculating power requirements can not be reduced to roughly 1.2 percent of the plant energy output, and the laser cost is roughly halved from the 0.12 mils/kW hr for a PFBC.

In presenting such a cycle, one primary concern is the ability of the resultant system to provide power at the time and in the form desired by the utility. This combined cycle offers one the opportunity to load follow during peak demand periods and effectively utilize capacity via high temperature electrolysis during periods of low demand. A combined cycle direct-fired turbine is the ideal system to apply to synfuel production as heat extraction in the radiant zone of the combustor is an integral component of the system. Raising steam in the combustor and generating electrical power via the gas turbine would remain the same for both modes of operation. However, the steam would be sent to a high temperature electrolysis unit whose electrical demands would be met by the gas turbine driven generator. A small, as yet undetermined, amount of steam would be run through the steam turbine to avoid having to shut it down completely. Customarily, such plants are seen to have an output energy split between the steam turbine and gas turbine of 2:1. Such a split would generate excess steam during periods of synfuel production if no electrical generation is required from the steam turbine. Therefore, an energy split closer to 1:2 might prove to be attractive during synfuel production. However, when a final decision is made, the specific utility would decide how much synfuel production is desirable.

Due to materials considerations in the high temperature electrolysis cells, an upper temperature limit needs to be imposed. In this application an upper limit of 1800 K for the steam temperature is assumed. At such an operating temperature the efficiency of the process to decompose water and form hydrogen would be less than that for direct coal gasification (e.g., 60 percent for the Lurgi process and roughly 52 percent for the present system). However, many of the components of the high temperature electrolysis system share their costs with the combined cycle electric generating plant. Therefore, the costs of synthetic gas fuels end up being quite similar ($\sim$ \$4.50/10^6 BTU).

The present scenario may be looked upon in a manner similar to energy storage. Both give a plant which is not operating in a base load configuration the opportunity to be operated at a higher capacity factor. Synfuel production, however, gives one the options of long-term energy storage and efficient consumption in a non-electric application. Indeed, hydrogen production might be a most inefficient means of electrical energy storage.

Controlling the turbine erosion problem in a direct-fired combined cycle plant via the introduction of a pressurized cyclone combustor and laser fragmentation would make such a system more economically viable. Synfuel production via high temperature electrolysis affords such a system greater flexibility for a utility to meet its demand and fully utilize equipment at the same time.

LOW-BTU COAL CHAR GASIFICATION BY A PRESSURIZED TWO-STAGE FLUIDIZED BED — SUNSHINE PROJECT —

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EXTENDED ABSTRACT

INTRODUCTION

A two-stage pressurized fluidized-bed coal char gasification process has been developed in the Government Industrial development Laboratory, Hokkaido, Japan, which is involved in the "Sun Shine Project" to provide coal conversion technology. The present paper describes the design and operation data so far obtained in the first stage of the process development program.

EXPERIMENTAL

Gasification experiments were conducted under the pressure up to 790 kPa and for temperatures between 1153 and 1323 K. The reactor was 75 mm i.d. and 1400 mm long and was divided into two-stages by a partition disc. The disc was designed to control compositions of coal char particles in both stages so that the heat required for endothermic gasification reaction in the second stage can be provided by the heat of combustion in the first. Silica sand particles were used as the refractory in the first stage. Coal char was produced by carbonizing the domestic Taiheiyo Coal at 773 K in a 300 mm dia. fluidized bed. Several properties of coal, coal char and silica sand used are summarized in Table 1(a) and (b).

RESULTS AND DISCUSSION

A preliminary experiment in a cold model was made to evaluate the effects of the partition disc on the char concentration profile along the height. The result is shown in Fig.1 which was obtained for the mixture of 40 wt% char and 60 wt% silica sand particles. It is shown that the discs used distribute about 17 wt% of char particles to the first stage and about 83 wt% to the second stage. This condition was desirable for the gasification in the second stage at higher temperatures and at the same time for stable fluidization of the ash-rich first-stage bed without ash agglomeration. Coal char was gasified with air and steam and experimental results showed that under conditions employed here all oxygen in air was completely consumed for the combustion within the first stage. Fig.2 shows the comparison of H_2 concentrations in both stages of the bed. The increased concentration of H_2 in the second stage suggests the progress of gasification in the stage as well as in the first. The heating value of produced gas was also shown to increase with the char feed rate, but there may be an optimum feed rate of char since the higher char feed rate causes more frequent ash agglomeration as well as less carbon conversion. At the moment gasification conversions attained in the second stage were fairly low because of the short residence time of the char. Modification of the present process in future is discussed in some detail on the basis of the results obtained here.

TABLE 1. PROPERTIES OF SOLIDS EMPLOYED IN THIS STUDY

(A) COAL AND COAL CHAR

		TAIHEIYO COAL	773K CHAR
PROXIMATE ANALYSIS (WT%)			
MOISTURE		4.7	3.0
ASH		10.2	15.7
VOLATILE MATTER		45.9	21.0
FIXED CARBON		39.2	59.4
ULTIMATE ANALYSIS (WT%)			
C		68.2	67.4
H		5.7	3.5
O		14.8	12.4
N		1.0	0.8
S		0.1	0.1
ASH		10.2	15.7
HIGH HEATING VALUE (MJ/kg)		27.1	27.5
u_{mf}	(m/s)	0.215	0.150
$\overline{D_p}$	(mm)	0.45	0.44
ρ_b	(kg/m^3)	650	380

(B) SILICA SAND

u_{mf}	(m/s)	0.27
$\overline{D_p}$	(mm)	0 50-0.71
ρ_b	(kg/m^3)	1300

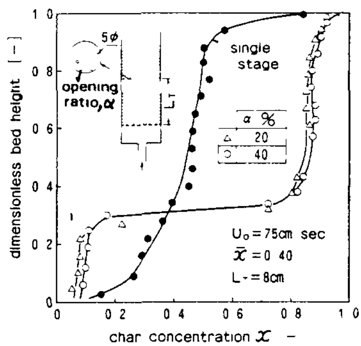

Fig.1 Effect of partition disc on segregation profiles

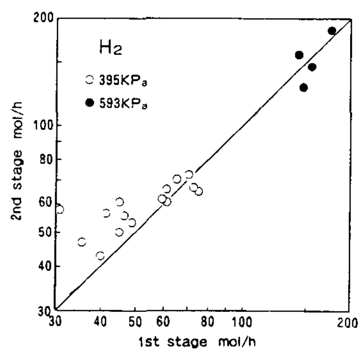

Fig.2 Comparison of H_2 concentration

EFFECT OF PARTICLE SIZE AND FLOW PARAMETERS ON THE RADIATION HEAT TRANSFER IN FLUIDIZED BEDS

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ABSTRACT

A parametric study is being performed in a range of temperatures from 500 to 1600°F, at pressures from 1 to 10 atms., in a one-foot diameter fluidized bed in order to understand the role of radiation heat transfer on the overall heat transfer coefficient. This study is being performed in order to provide a body of data that could be utilized in modelling of the entire heat transfer coefficient within a fluidized combustion facility. Limestone particles of various sizes (200 to 2000 microns) are used in order to determine whether particle size and superficial velocity have any effect (through the view factor) on the radiation component of heat transfer.

ECONOMIC ASPECTS OF COAL GASIFICATION IN BELGIUM

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EXTENDED ABSTRACT

INTRODUCTION

Thirty years ago, almost all the energy needs of Belgium were covered by coal. Gradually, almost all the coal mines had to close, under pressure of competitive oil prices.

ACTUAL STATE AND POSSIBILITIES OF TRADITIONAL COAL MINING IN BELGIUM

Despite the energy crisis, there is no possibility of restarting for the following reasons:

- lack of qualified manpower
- technical difficulties in re-opening the mines
- structural defaults and financial problems, that were responsible for ceasing activities in the past, have not disappeared today.

Maintaining the actual production in the traditional way (±7 million tons), does not seem a long term solution for the coal problem in Belgium.

Could new ways do better? Gasification, liquefaction, production of electricity, underground gasification? The general goal is to diminish the global deficit (supported by the taxpayer) through such new ways.

NEW WAYS OF COAL TRANSFORMATION - ECONOMIC RESULTS

The Belgian subsoil still contains considerable amounts of coal.

Coal Gasification (Surface)

Not one of the numerous ways of coal gasification is able to give good value for Belgian coal. An economic model was setup allowing:

- cost calculation of gas related to the global conversion output
- cost calculation of gas related to the price of coal utilized for the transformation
- cost calculation of gas related to the plant size.

To reach competitivity would require a departure cost of coal of about 25 to 30 dollars per ton, which is more or less one-third of the production cost for Belgian coal. This way could only aggravate the actual global deficit.

Coal Liquefaction

A model was setup, based on cost structures of foreign analyses. Sensitivity anlaysis shows tow important variables: conversion output, price of coal.

The result is uncompetitivity. Cost based on the use of Belgian coal is almost two times too high. Global deficit would rise from 200 million dollars to 350 million dollars.

Only imported cheap coal would lead to competitivity.

Underground Gasification under Variable Pressure

Considerable amounts of coal are still located between 1000 and 2000 meters underground.

The method consists of boring holes down to the layer(s) to be exploited, followed by a linking between the drillings, through a fluid injected into the layer under high pressure. Flaming the layer with the help of a comburent pushed into the introduction drillings, and recuperating gas under pressure at the outcome of the exploitation drillings. The gas would be used to furnish primary energy to an electrical plant unit.

Results based on the analysis of an economic model, rather sophisticated, were:

To reach competitivity, this means to produce a kwh at about 3 cents, the following conditions must be respected:

- minimum linking distance: 70 meters
- 60% of the disposable energy in situ have to be recuperated
- several layers, located on the same drilling, have to be exploited, in order to reach a minimum of four meters layer cumulated
- geological research, in order to ensure enough reserves for the whole lifecycle of the electric plant.

CONCLUSIONS

Under the hypothesis of a good world supply of coal, and the consecutive possibility of import at 30 dollars per ton, permanently, gasification or liquefaction could be competitive. Economic dependance subsists, but with a different and enlarged geographical origin, compared to oil only.

Under the hypothesis of good overwinning of still important technical obstacles for underground gasification, long term forecasts for energy sound quite good for Belgium.

SESSION 4E

HYDROGEN ENERGY III

ON-SITE PRODUCTION OF HYDROGEN FOR GENERATOR COOLING

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EXTENDED ABSTRACT

Hydrogen is currently used throughout the electric utility industry for the internal cooling of electric generators. The cooling system requires that a hydrogen reserve must always be kept on-site to maintain the daily hydrogen requirement for the generators. In addition, large quantities of hydrogen are also required to fill the generator after it has been out of service for repairs or on an extended scheduled maintenance or economy outage. In most cases, the necessary hydrogen is purchased from a vendor and stored on-site in a bank of high capacity cylinders for bulk storage or in bottles, depending upon the overall frequency and number of hydrogen deliveries required. Supplies may be costly and difficult to obtain due to local supply problems. The minimization of deliveries from the outside is also conducive to improving plant security and operating reliability.

In this paper we present our findings in favor of on-site production of hydrogen by water electrolysis as an alternative to purchasing hydrogen. The technical and economic feasibility as well as the advantages of installing an electrolyzer at a generating station to provide hydrogen for use in the generator cooling system are discussed. Our results are based on installing an electrolyzer at a specific generating station in the PSE&G system. The existing in-plant hydrogen system and the equipment retrofit needed to safely and economically manufacture hydrogen are described. Installation costs are shown as they pertain to this specific site in order to provide a more meaningful comparison with the costs of purchased gas.

In addition, we present scenarios based on manufacturing the gas using normal and off peak power and the possibilities of utilizing the gas for an in-plant burner ignition system, combustion modulation, and other uses. Costs and methods of gas compression and storage are described as well as in-plant uses of the by-product oxygen produced from the electrolytic process.

SOLID POLYMER ELECTROLYTE WATER ELECTROLYSIS HYDROGEN TECHNOLOGY DEVELOPMENT

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EXTENDED ABSTRACT

Electrolytic hydrogen can be used as an energy storage device for renewable energy sources which are periodic in nature or for chemical feed stock and mobile hydrogen.

General Electric in association with government and utilities has had a continuing four year technology development effort to reduce capitol cost and improve efficiency of solid polymer electrolyte water electrolyzers. Considerable progress has been made as shown in Figure 1.

The main cost and efficiency improvements are in the areas of current collector/separators, catalyst loadings, increased anode catalyst activity and improved configuration.

Collector/Separator The collector functions as a current transmitter, water and gas manifold and distribution member and must be corrosion resistant and non-contaminating with sufficient strength to contain high gas pressure at 300°F.

Previous aerospace collectors were constructed of metal sheets and screens with gasketed external and internal seals. The present collector is an integral unit with no gaskets and is made by compression molding. Initial molded collectors were made from graphite with a phenolic thermoset type binder with insitu forming of titanium foil for anode side protection.

With time it was found that the thermosetting resin contaminated the cathode catalyst causing excessive density. A fluoropolymer thermoplastic binder was developed which eliminated this contamination. Over 50 laboratory size (1/20 Ft^2) cells have proven the fluoropolymer collector/separators viability. The scaleup to 2.5 Ft^2 size has been successful.

Molded low cost collectors are now routinely fabricated for 2.5 Ft^2 modules at 1/8 the cost of the previous aerospace technology. Several innovations in manufacturing procedures have made this possible, mainly development of a short molding cycle of <6 minutes.

With the need for higher voltage efficiencies, the operating temperature was increased to 300°F (149°C) this necessitated the development of support structure for the hydrogen and oxygen sides to prevent the SPE from extruding into the grooves and blocking water and gas flow. Two hydrogen side supports were evaluated, both carbon based. A low cost random fiber mat was selected based on better spring and superior handling characteristics than a carbon powder mat.

Two types of anode supports, a perforated titanium foil (0.04 mm thick) and a porous titanium plate (0.2 mm thick), were evaluated at 149°C and found acceptable. The porous titanium plate has been selected based on lower cost and its additional strength allows more configurational design freedom.

Anode Catalyst Activity The anode oxygen evolution catalyst contributes the major portion of overvoltage effecting the efficiency. The development of a new anode catalyst, beyond the basic catalyst (designated E-50) has resulted in a reduction in cost, with an improvement in efficiency.

A ternary anode catalyst (designated WE-3) has demonstrated a 40 mv improvement in performance over E-50 at a cost reduction of 50%. WE-3 is firmly established as a replacement for the previous standard (E-50) as shown by the average performance of eight WE-3 cells in Figure 2. A newer binary catalyst has shown performance equivalent to E-50 with a cost 1/6 that of E-50. Development of this catalyst is continuing.

Catalyst Utilization Another aspect in reducing electrolyzer cost is lowering the amount of catalyst on both the anode and cathode. With ease of manufacturability of import. A method has been developed in 1/20 Ft^2 size hardware for direct application of catalyst to the SPE at a cost reduction of 90% that of baseline without loss in performance. This process offers lower cost and is amenable to large scale production. Scaleup to 2.5 Ft^2 size cells is presently in progress.

Life test performed on developed components (collectors and supports) have demonstrated over 5,000 hours of stable operation at 300°F and more than 15,000 hours at 180°F both at 1,000 ASF in laboratory hardware, as shown by the results in Figure 3. Advanced low loaded anode and cathode catalyst electrodes have demonstrated over 3,000 hours of stable performance at 180°F and 1,000 ASF.

Solid polymer electrolyte water electrolyzer cost and efficiency has been significantly improved during the technology development to date. The effort is continuing both in scale-up and in productionization of the processes for near term usage in commercial energy applications.

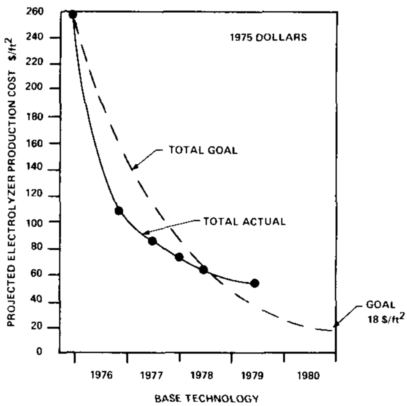

FIGURE 1 PROJECTED PRODUCTION COST – SPE ELECTROLYZER MODULE

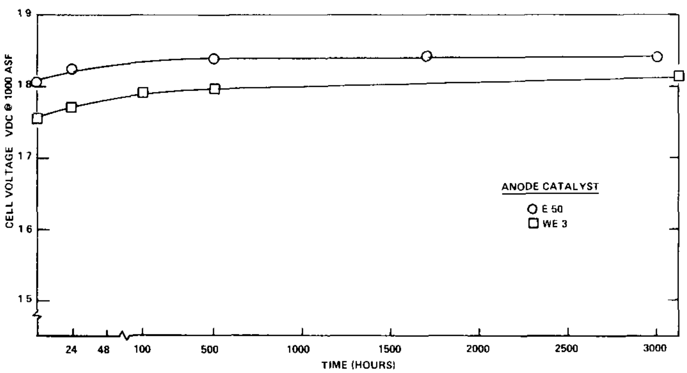

FIGURE 2 SOLID POLYMER ELECTROLYTE ELECTROLYSIS CATALYST ENDURANCE (180°F 1000 ASF)

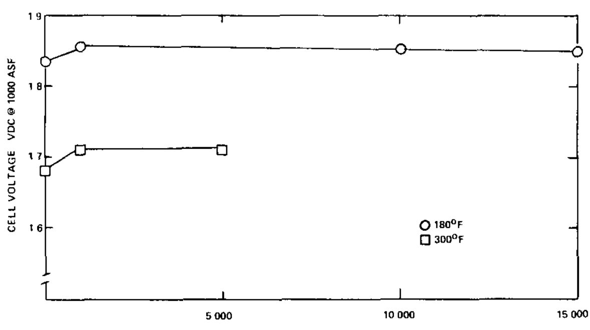

FIGURE 3 SOLID POLYMER ELECTROLYTE WATER ELECTROLYSIS ENDURANCE (1000 ASF)

GAS EVOLUTION DURING WATER ELECTROLYSIS

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ABSTRACT

Vapour bubble behaviour during nucleate boiling of binary systems is governed by combined heat and mass diffusion.
The following important special cases are incorporated:
(i) boiling of pure systems (heat diffusion)
(ii) electrolysis (mass diffusion).
The 'relaxation microlayer' (thermal boundary layer) theory for nucleate boiling of the author has been extended to electrolytic gas bubble evolution at an electrode, both for the cases of high and low Jakob numbers. Also, the analogy between the electrolytic gas production curve and the boiling curve is discussed.
Both hydrogen and oxygen bubbles are studied and theoretical predictions are compared with experimental results on:
(i) miniature electrodes, for which a 'total gas production' model has been developed
(ii) larger transparant electrodes.
The following parameters are varied: electric current density, Jakob number, pressure, supersaturation of the bulk liquid (both uniform and nonuniform), electrolyt composition, convection (natural and forced).
Motion pictures showing electrolytic gas evolution on electrodes will be shown.

ABSTRACT

HYDROGEN PRODUCTION SYSTEMS ANALYSIS

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An analytical tool for conducting trade-off studies for the design of electrolysis modules for use in hydrogen and/or oxygen production equipment has been developed and is discussed in this paper. The program developed provides for the evaluation of modules with circular or rectangular geometry, different capacities, module operating temperatures, and various gas delivery pressures. The relative merits of electrode options, electrode separator types, and other cell frame or seal material selections can be weighed against the principal common denominator--the total cost of hydrogen. While the program is currently configured to work with filter press type designs, much of the design methodology can be applied to other water electrolysis concepts.

The basic concepts and assumptions relative to electrolysis module design are described, first with respect to cell design, and second with respect to the cell stack assembly design. Generalized cell design is discussed where the cell geometry, active area, and internal pressure, are maintained as program variables. Building upon this, the problem of generalizing the cell stack assembly design is discussed with respect to cell to cell sealing, manifolding, end plate, and tie rod engineering. Having discussed the design interrelationships, the means for determining capital costs, operating efficiency, and product gas cost are reviewed. The flow chart that links the various program segments together is described briefly before proceeding with a brief sensitivity analysis.

A set of sample runs are presented showing the sensitivity of electrolysis module design to various changes in operating conditions and material selections. Three electrode options are discussed with respect to their impact on a system with a hydrogen capacity of 10,000 SCFH and with a delivery pressure of 150 psi. Next, the system design is impacted by allowing the cost of electricity to vary from 10 to 30 mils per

kilowatt hour. The other major parameters evaluated for impact are the capital equipment costs, the write-off period, the cost of money, and the electrolysis plant use factor. The last parameter investigated is the impact of internal gas generation pressure on the cost of hydrogen and a brief discussion of the effects of pressure on other components such as pumps, heat exchangers, and gas/liquid separators.

FUSION REACTORS FOR HYDROGEN PRODUCTION VIA ELECTROLYSIS*

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EXTENDED ABSTRACT

The production of synthetic fuels is an extremely promising and important application of fusion energy. Commercial fusion reactors are expected to begin operation by the early decades of the next century; at that point, oil and gas, which now account for ∿ 60 percent of the primary energy supply for the United States will not be an important source of energy. The critical need will then be for portable liquid and gaseous fuels which serve a myriad of uses--transport, space heating, process heat, chemical production, etc. There appears to be no shortage of inexhaustible energy technologies that can potentially meet U. S. electrical needs, including fusion, fission, solar photovoltaic, solar thermal, and hot rock geothermal, but very limited options for supplying portable fuels. Coal conversion is expected to be costly, and in the long run, may be restricted by environmental and supply factors. Inevitably, there may be a shift to an economy where hydrogen and hydrogen-based fuels, which will be derived from inexhaustible energy sources, play the major role.

Hydrogen can be produced from water by conventional low temperature electrolysis methods, but this route--which would use electricity from the inexhaustible energy sources--tends to be inefficient and expensive with conventional power cycles. The unique nature of fusion energy makes possible alternate routes based on thermal or a combination of thermal and chemical reactions for synthetic fuel production that are potentially more efficient and cheaper than conventional low temperature electrolysis. The temperature level available in a fusion blanket depends on choice of material; using ceramic or refractory blanket interiors, temperatures of ∿ 2000 °C appear achievable with inert gas coolants. Somewhat lower temperatures in the range of ∿ 1200 to 1500 °C appear necessary if chemically reactive coolants such as CO_2 or steam are used, based on materials compatibility experiments carried out. In addition to high temperature thermal process uniquely suited to fusion, there are radiolytically based processes that can directly transform neutron and gamma energy into chemical energy for fuels production although efficiencies tend to be relatively low.

*Work performed under the auspices of The Department of Energy.

There are a number of processes now being considered for synthetic fuels production from fusion energy. Of the alternatives to low temperature electrolysis (LTE), high temperature electrolysis (HTE) of steam is the most developed, and has the highest potential efficiency. In HTE, a large fraction--$\sim$ 30 to 50 percent depending on temperature--of the energy to dissociate water is supplied as high temperature heat rather than electricity. This results in a very high process efficiency, e.g., $\sim$ 50 to 70 percent based on temperature and power cycle efficiency. The process efficiency is defined as the chemical energy in the generated hydrogen [at the higher heating value (HHV)] divided by the total fusion energy release, including alpha particles and secondary neutron reactions in the blanket. Both high and low temperature blanket heats are counted as part of total fusion energy release. In addition, the low temperature blanket heat in an HTE based reactor can be effectively used to generate electricity needed in the HTE process, where in general, only the high temperature blanket heat can be used in thermochemical or thermal decomposition processes. Low temperature heat would have to be used to generate electricity either as a coproduct or to produce H_2 by an LTE process.

LTE combined with an advanced high efficiency power cycle, for which fusion appears uniquely capable, is a very attractive option, with high efficiency $\sim$ 55 percent for H_2 production and relatively simple technology. Both LTE and HTE processes offer the potential for dual product production, electricity and synfuels, with the proportions capable of being adjusted on a daily or longer basis to meet varying demand conditions.

As a transition step to a hydrogen based fuels economy with H_2 and H_2 derived fuels using a non-fossil source of carbon (e.g., from atmospheric CO_2), hydrogen produced by water splitting in reactors can be used in conjunction with coal gasification and liquefaction processes. The amount of coal feed can be greatly reduced (e.g., by a factor of 3 for SNG production), which would conserve coal resources, reduce CO_2 emissions, and reduce coal feed costs.

Overall, the technology of fusion synfuels production appears quite promising, with high potential efficiency and reasonable cost.

JF

CO/H_2 PRODUCTION USING FUSION REACTOR HEAT*

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EXTENDED ABSTRACT

Several alternative methods for producing H_2 have been proposed, including both low and high temperature electrolysis of water, several thermochemical cycles and thermal dissociation of water. This paper presents the details of a process in which CO_2 is partially dissociated into CO and O_2 at high temperatures. The CO so produced is then separated from O_2 and CO_2 and reacted with steam in a "water gas shift" reactor to form H_2 and CO_2. Since the CO_2 is reformed, water is the primary feed reactant in the process. A major advantage of this process is that the temperatures between 2500 and 3000 °K required to achieve significant thermal dissociation yields (up to 25 percent dissociation) are significantly lower than those required in the thermal dissociation of water to give the same yield and can be generated easily using non-steady gas dynamic processes.

The process we are studying is depicted in Figure 1. A stream of CO_2 and He coolant is fed into the high temperature (> 2000 °K) blanket

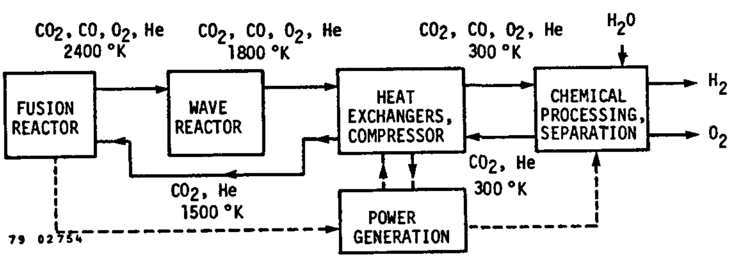

Figure 1. Schematic Diagram of H_2 Chemical Processing Cycle

*Supported by the U.S. Department of Energy under Contract No. ET-78-C-06-1095

of a fusion reactor. The coolant is heated and partially dissociated by the thermal energy deposited by the high energy neutrons from the fusion reaction. Blanket coolant exit temperatures of 2400 °K result in a carbon monoxide mole fraction of about 4 percent. The coolant then enters an "unsteady wave chemical reactor" where it is further heated and compressed to near 3000 °K and 10 atmospheres. Yields of CO in excess of 15 percent are achievable at these conditions. (An unsteady wave chemical reactor is an array of shock tubes on the periphery of a rotating drum which allows the processing of gas streams on a continuous rather than pulsed basis.) The gas mixture of CO, O_2 and CO_2 once equilibrated is rapidly re-expanded in the wave reactor using unsteady expansion waves to temperatures near 1800 °K. This rapid cooling (> 10^6 °K/sec) achievable only by unsteady gas dynamic waves prevents the chemical recombination of CO and O_2 and represents the key to the success of the overall cycle.

Once the gas mixture leaves the wave reactor, it is further cooled in heat exchangers to near ambient temperatures. The CO is then separated from the other gas components using standard cryogenic processes. Once separated, the CO is reacted with steam at about 600 °K in the "water gas shift" reactor to form H_2, the desired end product. CO_2 is also reformed in the shift process. The H_2 and CO_2 are then separated and dried with the CO_2 being recombined with the previously separated CO_2 and He. The gas mixture is then reused as a coolant for the fusion reactor blanket.

The paper discusses the important features of each major component in the process. Included will be discussions of component energy balance, component gas flows, component design concepts, component efficiency, and preliminary estimates of the economics of producing H_2 using this process. Preliminary calculations indicate that a site energy efficiency of near 35 percent and an H_2 flow rate of 5090 moles/sec are achievable by using a 4000 MW thermal fusion reactor as the base component in the process. The factors which determine this efficiency and how this efficiency might be increased are also discussed.

THE MARKET POTENTIAL FOR ELECTROLYTIC HYDROGEN*

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EXTENDED ABSTRACT

Though the economics of hydrogen production by the major users of hydrogen (petroleum refiners and manufacturers of ammonia and methanol) favors the continued use of fossil fuels for hydrogen generation, there are a large number of miscellaneous (specialty) small users for whom hydrogen produced by advanced electrolyzers may become economically attractive. Many of these small users, with hydrogen demands of less than 0.5 million SCF per day, purchase their hydrogen requirements from industrial gas suppliers. Forseeable improvements in current electrolyzer technology, which will greatly reduce plant capital costs and significantly improve plant performance and efficiency, may make electrolytic hydrogen competitive with purchased (merchant) hydrogen for many specialty users.

The analysis of this study indicates that for annual demands of less than 100 million SCF, electrolysis using advanced electrolyzer technology will be competitive with steam reforming of either natural gas or naphtha. For annual hydrogen requirements much greater than 100 million SCF per year, steam reforming will continue to have economic advantage over electrolysis. While relative differences in the escalation of the real cost of electricity and fossil fuels will determine the competitive crossover point for any given application, the lower capital costs projected for advanced electrolyzer technology will make electrolysis particularly attractive for small plants where the economies of scale for reformers are lost.

Hydrogen demands of much less than 100 million SCF per year often are met by hydrogen purchased from an industrial gas supplier (merchant hydrogen). Deliveries of merchant hydrogen are made in individual pressurized gas cylinders, pressurized gas tube trailers, or in liquid tankers for on-site conversion to gas. The anticipated improvements in electrolyzer technology will make electrolytic hydrogen competitive with merchant hydrogen for virtually all specialty requirements.

The principal specialty users for hydrogen are found in six product categories: chemicals, pharmaceuticals, foods, metals, electronics, and

*The work reported in this paper was supported by a contract from The Electric Power Research Institute, Palo Alto, CA.

float glass. In the synthesis of chemicals, in the manufacture of pharmaceuticals, and in the hydrogenation of edible fats and oils, hydrogen is consumed as a process feedstock. In the metals industry, hydrogen is used as a reductant in refining certain nonferrous metals and as the component of atmospheres used in heat treating. Hydrogen also is used to provide protective atmospheres for the production of semiconductors in the electronics industry, and for the manufacture of float glass by flat glass manufacturers.

For specialty users being supplied with merchant hydrogen, the decision to switch to on-site hydrogen production by electrolysis will be governed primarily by the realization of potential annual savings. Very small users (under 1 million SCF of hydrogen per year) may find that even substantial differences between the cost of purchased hydrogen and the cost of electrolytic hydrogen for the volumes used do not provide sufficient total annual savings (e.g., in relation to final product earnings) to make them want to engage in hydrogen production. Many of these small users have intermittent hydrogen demands, and the resulting low plant capacity factors can erode the economic advantage of electrolysis.

Table 1 shows the projections for the total potential electrolytic hydrogen demand to the year 2000 for each of the industrial market segments. By the end of the century the potential market for electrolytic hydrogen among specialty users is projected to be about half of what the merchant hydrogen market would be in the absence of electrolytic hydrogen. This potential market, representing an annual demand of about 16 billion SCF, will develop from market penetrations of electrolyzers assumed to begin in the early 1980s. The projections, however, do not represent forecasts of sales. What fraction of the market will be achieved, given the development of advanced electrolyzer technology, will depend in large part upon the production and merchandising efforts of electrolyzer manufacturers and the quality of performance and reliability of commercial units. The potential market represents what may be achieved by assuming the maximum probable rate of penetration.

TABLE 1. TOTAL POTENTIAL DEMAND FOR ELECTROLYTIC HYDROGEN AMONG IDENTIFIED SMALL USERS

	(Billion SCF) 1985	1990	1995	2000
Chemicals	.41	1.2	3.3	9.7
Pharmaceuticals	.01	.02	.08	.24
Fats and oils	.08	.18	.41	.93
Metals	.12	.30	.78	2.0
Electronics	.09	.24	.64	1.76
Float Glass	.06	.15	.38	1.0
Electric Generator Cooling	.02	.05	.15	.4
Total	.8	2.1	5.7	16.0

The most likely initial markets for advanced electrolyzers probably will be found among food hydrogenators and in the chemical industry. While larger plants in these industries generate their hydrogen needs by steam reforming, smaller plants, presently being supplied with merchant hydrogen, are believed amenable to using electrolysis if economic advantages can be demonstrated.

Electric utilities may find it attractive to produce hydrogen needed for generator cooling. Experience with reliable on-site advanced electrolyzers may encourage utilities to consider their role in serving the demand for electrolytic hydrogen. Utilities who see long-term possibilities for hydrogen as a storable and transportable energy carrier can be expected to be interested in the successful development of advanced electrolyzer technologies, and to seek possibilities for gaining experience with advanced electrolyzers.

AUTOMOTIVE DUAL-MODE HYDROGEN GENERATION SYSTEM

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EXTENDED ABSTRACT

Introduction

The present state of the art of automotive hydrogen power is generally limited to the metal hydride storage means of hydrogen gas on-board the vehicle. Hydrogen is supplied from dispersed storage stations, or by home electrolysis units. The total reliance on hydrogen on-board storage will drastically limit the performance versatility and range of the vehicle. This will make hydrogen as an automotive power source, far less attractive than is possible to achieve eventually.

Some type of on-board hydrogen generation arrangement should be made an integral part of any total hydrogen/automotive fuel system, if hydrogen is to gain acceptance as a viable and economical alternate to gasoline in the decades ahead. With ever increasing gasoline costs, alternate fuels, including hydrogen, must prove themselves to be practical and better than competitive, if they are to gain wide acceptance.

Status

The automotive/hydrogen field is one of several current areas which is characterized by a consistant lack of imagination, inititive and steady, diverse development effort.

BACKGROUND

Various types of automotive on-board hydrogen generating means have been proposed and built over the years with the prospects of utilizing this effective and desirable non-polluting fuel. All the retrofitted equipment proposed was based on three known methods which are: 1) electrolysis of water, including hydrogen generated by the vehicle's primary battery, 2) the reforming of gasoline process, and 3) a modified steam-on-iron process. There may be other automotive/hydrogen producing methods, but they are more obscure with less liklihood for success, or are still in the experimental stages of development.

In reviewing the relative value of these three known on-board automotive hydrogen producing methods, several advantages and disadvantages become apparent as each is considered. While electrolysis of water is dependable and produces high purity hydrogen gas, it requires a relatively large amount of electrical current input. Also, it has a slow rate of gas generation so that it is not suitable for automotive applications.

The reforming of gasoline process can be viewed as less than desirable economically for automobiles. A portion of the gasoline which we are attempting to conserve is used for the reforming of gasoline into the various hydrocarbons.

The steam-on-iron process for automotive applications has yet to be proven practical due to the major problems of on-board steam generation. The large iron contact mass usually required, plus the periodic purging of the iron mass needed for nearly uninterrupted hydrogen generation is one problem area.

Although not generally regarded as a competitive hydrogen generation means at this time, the permeation of either hydrogen or oxygen from steam through a suitable membrane may eventually be developed to a point of economic feasibility. The main problem with the permeation of gases through a membrane is the slow rate of gas passage with a large surface area required for a modest gas flow volume.

DESCRIPTION

The present automotive, dual-mode hydrogen generation system consists of combining two of the previously described methods of hydrogen generation. Each compliments and supports the shortcomings of the other. The gas permeation and steam-on-iron process will be utilized, since they both pass or absorb oxygen from a steam flow. However, they must be used in that order respectively, since one is clean and the other is not.

The key to the practical economics of the gas permeation method is that oxygen rather than hydrogen gas must be removed from the steam flow. It is uneconomical to remove hydrogen directly from the steam flow because of the high cost of palladium or rare earths which would have to be employed.

To make the permeation of oxygen mode of operation practical, a single thin silicone rubber membrane will be exposed to steam flow within a long, narrow, spiral path, half-tubing loop. A long, narrow permeation path is provided for the progressive passage of oxygen from the steam. Although only a small percentage of oxygen will be removed from the steam flow by way of this permeation mode, the steam flow will be clean when it enters the second mode modified steam-on-iron reactor cylinder(s). A patent application has been filed on a manifold generator unit which offers a possible solution to the formidable problems facing the adaptation of the large-scale industrial steam-on-iron process to the small scale automotive/hydrogen application.

Taking some of the problems in turn, the steam for the automotive/hydrogen second mode process is produced by using small diameter copper tubing coils closely fitted over the exhaust manifold(s) of the vehicle's engine. The water which enters the tubing to produce the steam is gravity fed from plastic containers conveniently located within the engine compartment. The small steam flow produced is directed into one or two reactor cylinders containing rotating wire brushes. The iron wires forming the dense rotating brushes will become progressively oxidized as the steam flow passes through them, thus, removing oxygen from the steam flow. A relatively large number of iron wire brushes are uniformly spaced within the inner diameter of the reactor cylinder(s) to aid in meeting the large contact mass area required for this automotive/hydrogen process.

The periodic purging will be accomplished by aeration on an intermittent rotation of all the wire brushes. A final steam reforming stage of the partially reformed steam to hydrogen flow is achieved by steel wool packs which are also periodically replaced.

SESSION 4F

ECONOMICS AND POLICY IV

FORECASTS OF ENERGY SUPPLY AND DEMAND 1979-1995

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ABSTRACT

Forecasts developed by the Energy Information Administration within the Department of Energy for the Annual Report to Congress, July 1979 are presented and analyzed. Five scenarios are discussed which cover the range of supply and demand possibilities, including high and low assumptions concerning energy resource availabilities, resource recovery costs, macroeconomic conditions, and the price of imported oil. Emphasis is placed on analysis of energy consumption, impacts of conservation programs, and the penetration of new technologies.

Energy consumption forecasts are discussed by sectors; residential, commercial, industrial, and transportation. In the residential sector, growth in the housing stock, the market penetration of home appliances and conservation equipment, escalation in energy prices, and the modest entrance of renewable resources are the principal determining factors of energy use. Impacts of the conservation programs set forth in the National Energy Conservation Policy (NECPA) of 1978 such as appliance efficiency standards and the residential tax credit, will be substantial in this sector.

In the commercial sector, growth in building floor space tempered by escalation in fuel prices and the adoption of energy conservation equipment and procedures, are the principal determining factors of energy use. Again, impacts from NECPA will be substantial.

In the industrial sector, growth in value added counteracted by improved energy use efficiencies will be the principal determining factors of total energy use. The mix of fuels, however, will be substantially affected by new regulations promulgated as a result of the Powerplant and Fuel Use Act of 1978 and the National Gas Policy Act of 1978. The first law restricts use of oil and gas in large boilers and the second law imposes a form of incremental pricing on industrial natural gas use.

In the transportation sector, growth in income tempered by escalating gasoline prices, increases in the fuel efficiency of new cars, and the market penetration of diesel vehicles, will be the principal determining factors of energy use. The newly enacted gas guzzler tax will have minimal impacts.

Results are presented in a series of tables and graphs. An example is provided in the attached table showing historical and projected net energy consumption and prices by economic sector. Energy use in the residential, commerical, and transportation sector will experience a moderation in growth due to escalating energy prices and the impacts of energy efficiency standards applied to building and vehicles. Energy use in the industrial sector is expected to increase at 3 to 3.5 annual rate of growth due, principally, to a projected wth rate of 4.4 percent annually in industrial value added.

Energy Information Administration
April, 1979

PRELIMINARY RESULTS
Not for quotation

HISTORICAL AND PROJECTED NET ENERGY CONSUMPTION AND PRICES BY ECONOMIC SECTOR*

Sectors	1962	1972	1977	1985 Low	1985 High	1990 Low	1990 High	1995 Low	1995 High
				Consumption Levels					
Residential									
Consumption (10^{15} Btus)	7755	10544	10293	10479	10848	11056	11793	11486	12526
Prices (1978 $)	3.48	3.28	4.73	6.63	5.68	7.42	6.06	8.78	6.57
Commercial									
Consumption (10^{15} Btus)	4716	7768	7866	7136	8189	7305	8949	7573	9899
Prices (1978 $)	3.61	3.21	4.95	7.67	6.60	8.27	7.18	9.19	7.88
Industrial									
Consumption (10^{15} Btus)	17162	22627	22155	26885	29225	30678	35751	36413	43185
Prices (1978 $)	1.41	1.48	2.51	3.86	3.41	4.51	3.68	4.98	4.01
Transportation									
Consumption (10^{15} Btus)	11251	18146	20151	19306	21719	19417	24182	20365	27256
Prices (1978 $)	4.33	3.82	4.83	6.31	5.96	6.98	6.10	7.80	6.76
Total									
Consumption (10^{15} Btus)	40884	59085	60465	63806	69981	68456	80675	75837	92866
Prices (1978 $)	**	**	**	**	**	**	**	**	**

* Energy consumption in this table is the amount consumed by the end-using sectors; it does not include losses at electric generating plants or losses in the transmission and distribution networks.

** Not yet available.

THE ECONOMIC AND SOCIAL COSTS OF COAL GASIFICATION VS. COAL ELECTRICITY FOR PROVIDING SPACE HEAT TO THE CENTRAL U.S.

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EXTENDED ABSTRACT

INTRODUCTION

Due primarily to geographic factors, opportunities for economical substitution of coal for other scarce fuels are greatest in the Central U.S. The region is heavily dependent on natural gas. The response to anticipated increases in gas cost and decreases in gas supply is twofold: (1) coal is being substituted for natural gas as an electric utility fuel, (2) electricity is being substituted for natural gas as a heating fuel. These steps accomplish a substitution of coal for natural gas. As a result, there is a boom in coal mining and coal electric power plant construction in the region. This boom is causing rapid population growth and consequent negative socioeconomic (boom town) impacts in many rural areas.

This study addresses both economic and socioeconomic issues concerning the substitution of coal for natural gas as a heating fuel in the Central U.S. The most probable alternatives for this substitution are coal based electricity and high-Btu coal gasification. Previous research demonstrates that the current increased use of coal-electric-based heat is now economically desirable in most of the region [1]. However, that same research shows that coal gasification will become the more economical alternative in most areas if current trends continue. This paper refines a previously developed evaluation of coal related socioeconomic impacts [2]. It is found that the lesser socioeconomic impact is consistently associated with the more economical alternative.

METHODS

Economic Evaluations. The primary determinant of relative economic viability of the two coal alternatives is the question of whether or not excess winter electric utility capacity is available. If so, then the electric utility could sell electricity for only operating costs. In this event, coal-electric-based heat is the more economical alternative. Much of the Central U.S. currently has excess winter electric capacity. Current increases in electric heating installation rates are therefore a desirable way to convert to coal use. However, by examination of the engineering behavior of the electric and gasification pathways as a function of climate and by projections of the current rates of electric heating installation, it is shown that coal gasification will increasingly become the more economical alternative.

Socioeconomic Effects. In the short run, the coal electric option will cause the lesser socioeconomic effect for two reasons: (1) it is more efficient and causes less coal mining and (2) duplicate gasification facilities are not built when electrical capacity is available. In the long run, however, the relative socioeconomic impacts of the two technologies are far more diffi[cult] to determine. When new capacity is necessary for either technology, then there are two critical factors determining degree of socioeconomic impact. The first is the average facility's labor requirements. The second factor is the number of workers available within commuting range of the facility. By using technical requirements for capacity of electric or gasification plants to provide equal amounts of heat, it is demonstrated that electric plants will require far more workers. However, by examining siting patterns for the two types of plants, it is determined that gasification plants are far more likely to be sited in remote rural areas where few local workers are available and relatively large in-migration of construction workers is necessary. The probability of joint plant-mine siting is compared for both technologies and the total coal mining labor and siting needs are discussed. An impact index is constructed to take account of the relative importance of each factor.

RESULTS

When excess winter generating capacity is available, it is less costly to shift to electric heat than to maintain gas use by coal gasification. Because less plant construction and mining occurs in this case, the socioeconomic impacts are also less. Since most states, except those in the far north, currently have summer peaking electrical utilities, the present trend toward electric heating in new homes in conjunction with construction of (or conversion to) coal electric power is desirable. These trends, however, will ultimately lead to an expansion of the number of states with winter peaking utilities southward as far as Oklahoma. At the time when utilities are winter peaking and new electric construction is for heating purposes only, then coal gasification is a more economical alternative. The construction of a socioeconomic impact index for this case indicates that the coal gasification alternative will then cause the least socioeconomic impact. These results demonstrate that the appropriate coal-based heating technology for the Central U.S. can vary both in time and space, due to sensitivity to regional variations in climate and to temporal variations in installation rates of heating and cooling equipment.

CONCLUSION

The results suggest that coal gasification may already be the more desirable means of using coal for space heating in the northern areas of the Central U.S. Current electric heat installation trends indicate a slow southward expansion of the geographic area to which this conclusion applies.

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ENVIRONMENTAL CONCERNS ASSOCIATED WITH DISPOSAL OF MINED WASTES FROM COMPRESSED AIR ENERGY STORAGE CAVERNS

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A signigicant portion of the future total peaking energy supply of the U.S. may be supplied by Compressed Air Energy Storage (CAES). As the lead laboratory for the Department of Energy's CAES program, the Pacific Northwest Laboratory is involved not only in the technology development of CAES, but also in the environmental concerns associated with this type of energy storage. The objectives of the CAES Environmental Control Concerns project are to investigate the potential environmental impacts of CAES facilities and to develop a data base of environmental control factors for this energy storage technology.

An initial step in the evolution of this project was completion of a Management Program Plan. This document outlines the research and development efforts needed to characterize the differential impacts between CAES technology and conventional gas turbine technology for meeting the peaking requirements of base-load electrical generating plants.

Two potential storage media for the compressed air include hard rock, and salt deposits. (A third is storage in a porous medium). If hard rock is conventionally mined to provide a storage cavern for the CAES facility, then as much as one million cubic meters of hard-rock mine tailings will be placed on the grou surface. Two immediate environmental concerns occur in this case: (1) Disposal of the tailings, and (2) Potential contamination of the biosphere due to leachin of toxic substances from the mine tailings. Research was instituted into the techniques of the mining industry for controlling the leaching processes and the dispersal of leachates.

Development of a CAES cavern by solution mining of a salt deposit creates brine disposal problems. One disposal technique is to inject the brine into a nearby underground saline formation, but several environmental concerns arise regarding this disposal technique: (1) How much brine can be injected safely? (2) What should the maximum injection pressure be? (3) Under what conditions will injection cause hydrofracturing of the saline formation confining strata? (4) What might be the effects of a difference in salinity between the brine and the disposal formation? A study of this disposal technique was instituted to determine: (1) The applicability of this technique to CAES; (2) The effects of EPA regulations on brine disposal by injection; and (3) the alternative methods of brine disposal.

INTERNATIONALLY SAFEGUARDED ATOMIC FUEL EXCHANGE CENTER FOR THE ASIA-PACIFIC BASIN (APB)

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EXTENDED ABSTRACT

There have been a number of proposals offered regarding the international management of strategic nuclear materials dating back to the post-war era and the Bernard Baruch plan which called for international ownership of all strategic nuclear facilities and materials. The concept of internationally controlled fuel cycle centers serving the need of several countries has recently been revived and the IAEA has taken the leading role in studying this concept [1].

The nuclear capability of the APB is summarized in Table 1. Besides the existence of uranium and thorium reserves, and the possession of either research or power reactors, an attempt has been made to assess the technological capability of these countries to carry out reprocessing, enrichment, fuel fabrication and waste management. Their status of participation in the Non-Proliferation Treaty (NPT) is also noted.

The establishment of an ISAFE Center in the Asian Pacific Basin will have to be decided after optimizing all considerations. Some of the criteria that should be considered in setting up such an institution are listed in Table 2. The criteria to be considered can be divided into two categories: Flexible and inflexible. Whereas the criterion like financial arrangements will have to be decided only after detailed negotiations among the participating nations, geologic site considerations must meet at least minimum safety standards, and thus is considered an inflexible criterion. Yet other criteria, like transportation, may have flexible and inflexible components to them.

With the exception of Japan, none of the Asia Pacific Basin countries appear to be likely candidates for Pu utilization within this country. Therefore, if the ISAFE Center returns to its member states only UO_2 fuel,there will be an accumulation of Pu at the Center. Since Pu is a strategic nuclear material, its proper management will be of concern not only to member states, but also to other nations in the world.

A separate set of siting criteria has been developed, and are summarized in Table 3. These criteria are intended to aid policy-makers and researchers in narrowing the number of choices for each center. A multiple-objective decision analysis methodology for choice of spent fuel storage sites was developed and Palmyra Island found by the analysis to be the most suitable. These results are shown in Table 4.

From an idealistic viewpoint of international cooperation, it may be feasible to find a number of nations to agree on a method for establishing an international nuclear fuel cycle center in the Asia-Pacific Basin after a period of time and effort is expended. However, it may be a better strategy and more rapidly establish such cooperation if a step-by-step basis is initiated by a few leading nuclear power countries in the region, and later bring in the additional countries as they require nuclear services from such facilities.

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	Japan	South Korea	North Korea	People's Republic of China	Republic of China (Taiwan)	Vietnam	Democratic Kampuchea	Thailand	Malaysia	Hong Kong	Singapore	Indonesia	Philippines	Australia	New Zealand	Fiji	Brunei	Lao People's Democratic Republic	Papua New Guinea	Samoa	Tonga	Trust Territories of the Pacific
Uranium Reserves	X	X		P								X		X								
Thorium Reserves		X		P					X					X								
Uranium Mining and Milling Capability	X	X	?	X	?									X								
Fuel Fabrication	X													?								
Enrichment	X			X	?									?								
Research Reactor	X			P	X			X		O		X	X	X								
Power Reactor	X	C		?	C								C									
Reactor Construction	X	?	?	?										?								
Reprocessing	X	?		P	X									?								
Waste Management	?													?								
NPT Status	S	S			SR	1	2	A	SR		S	S	SR	SR	SR	A		3			A	

S. Signed

SR Signed and ratified

1 Signed by South Vietnam in 7/1/68

2. Accession by Khmer Republic in 6/2/72

A Accession

3 Signed and ratified in 7/1/68 and 2/20/70 respectively by Laos

C Under construction

0 On order

? Uncertain/questionable

P Probable

GSS

TABLE 2: Criteria for Establishment of ISAFE Center

1. Flexible Criteria

   Host Country
   Financial Arrangements
   Legal Arrangements
   Institutional Arrangements
   Transportation
   Waste Disposal
   Conditions of Technology Transfer
   Range of Operations and Size

2. Inflexible Criteria

   Geologic Site Considerations
   Transportation
   Waste Disposal
   Proliferation-resistant Fuel Type
   Member states forgo national facilities
   Acceptance of multilateral safeguards inspection
   Disposal of Pu

TABLE 3: Primary Requirements for Siting in APB Islands

1. Uninhabited, not too close to any large populated islands, and not belonging to a state of the U.S.A.
2. Should not be near territories used for nuclear testing or any Trust Territories which do not belong to the U.S.
3. Should have undisputed U.S. territorial ownership.
4. Should not be of great resource or military value.
5. Area of at least half a square mile (160 acres).
6. Should have a natural harbor or a reef or other projections which would make it suitable for creating a harbor.
7. Air accessibility.
8. Near geometrical center of spent fuel generation sites.
9. Fresh water supply.
10. Geological and climatological stability.

Table 4. Computed Site Acceptability and Performance Index Values

	P. I. $= \Sigma \vec{W} \cdot \vec{R}_i$	$\pi_i A_i$	SAPI
American Samoa	172	0	0
Swains Islands	216	0	0
Guam	172	0	0
Midway	175	0	0
Wake Island	175	0	0
Johnston	225	0	0
Sand	270	1	270
Kingman	293	0	0
Palmyra	340	1	340
Howland	318	1	318
Baker	318	1	318
Jarvis	318	1	318

OPTIMUM DESIGN CRITERIA OF ENERGY CONSERVATION METHODS FOR BUILDINGS

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EXTENDED ABSTRACT

INTRODUCTION

In a summary on energy consumption in buildings within the ten 'Composite'* nations, Fish(1) found that building was responsible for about 40% of the primary energy which was consumed. This percentage is rather high as the world's energy demand is escalating in other areas such as transportation, agriculture, and commerce. It is therefore essential that adequate energy conservation measures are taken in buildings in order to minimise its huge consumption.

In order to ascertain the magnitude of energy conservation action which could be taken in buildings, it is important that the basic principles of building design and patterns of energy use in buidings are well understood. The climatic effects on buildings are also very essential aspect to be considered.

BUILDING DESIGN

Buildings could be designed(2) in such a way that environmental comfort may be achieved without massive utilisation of primary energy sources. The principal factors which affect the heat balance of a building are:

(a) Orientation
(b) Solar heat gains
(c) Ventilation losses
(d) Shading
(e) Thermal properties of construction materials used.

Orientation of buildings will influence their indoor climate due to the action of solar radiation and ventilation. Solar radiation affects a building in two ways:

(1) Emmission through window and absorption by internal surfaces in the building,
(2) By the external surfaces absorbing solar heat and transfering this into the interior.

It is generally practicable to minimise solar transmission through windows if adequate shading devices are used(3). External shading devices are usually effective and are in the form of overhangs, awning, trees and shrubs.

The thermal properties of the building materials has effect in the heat balance of the building. The designer should therefore pay adequate attention to the choice of material to be used.

PATTERN OF ENERGY USE IN BUILDINGS

In conservation of energy in buildings, it is essential to take adequate care of energy which is consumed in the building by the occupants. These fall within the following categories:

1) Household energy consumption for lighting.
2) Energy for production of hot water.
3) Air conditioning.
4) Space heating.
5) Refrigeration.
6) Cooking
7) Washing and drying.
8) Other household garjects which consume energy.

Each of the above factors will be examined in details in the final full-length paper. However, as the current increase in energy costs has however resulted in a keen interest being given to the energy conservation in areas of heating and hot water production, a special reference will be made to these. For example, in the developed countries water demand in most homes is within 700 and 1200 litres per week. It is essential to adopt effecient hot water production technique in order to maximise the saving on primary energy. Several factors will influence production of hot water at high efficiency. The principal ones are :

(a) Heat losses which can be reduced by the application of improved insulation.
(b) Heat losses which can be reduced by cutting down the on/off cycling of the boiler on its own thermostat.

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* Ten nations which submitted 'country monographs' to the CIB Energy Conservation Symposium 1976: Belgium, Canada, Denmark, France, Ireland, The Netherlands, Norway, Sweden, United Kingdom, and the United States of America.

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A LONG TERM ENERGY SCENARIO

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EXTENDED ABSTRACT

INTRODUCTION

This paper pertains to an examination of the status of the long term energy supply and demand. An arbitrary time span is set up as follows:

1. present
2. near term: upto 2050
3. long term: beyond 2050

The year 2050 is chosen as the reference point because of the anticipated fusion reactor power production.

Our analysis is based on the premises that government regulations and political decisions, while influential and ponderous at present and in the near future, can not compet with basic human and economical nature in the long run. Conservation measures are against human nature and economic development. Such measures are therefore doomed to failure and will cause irregular economic development pattern. Thus, in long term analysis, these measures will not play any significant role. A more far-sighted approach of the energy problem must rest on following the natural development pattern based on the human urge and need to improve the living standard. Governmental actions should be designed to gently guiding all sectors to follow such natural development, not forcefully and abruptly to mandate changing course from the trend. In fact, it is our contention that if proper actions are not taken in time, wholesale social, political, and economical upheaval would occur in the future due to energy supply and demand abnormalities.

A qualitative review of the present energy reserve and technology is conducted. The energy end-use analysis is performed for each of the four catagories: the private sector; the commercial and industrial sector; and the electric power production. Future energy needs for each of the three periods are predicted. Based on these studies, we are constructing a scenario describing the long term energy situation.

SUMMARY

The long term energy scenario, as we see it, is summarized in the following table.

TABLE 1: ENERGY SCENE

	Present	Near Term	Long Term
Private Sector:	oil, gas, electric,	oil, gas, solar, electric	solar, electric,
Commercial and Industry :	coal, electric, oil, gas, solar,	coal, electric, oil, gas, solar	electric,
Transportation:	oil, electric,	oil, electric,	electric,
Electricity :	coal, gas, oil, fission	coal, fission	fusion

In the long run, it is inevitable that solar and fusion energy will supply major portions of the energy demand. Solar energy will be mainly used in private sector as supplimentary and small unit energy sources. Fusion energy is basically for large scale applications. The great majority of the electricity production will be from nuclear fusion reactors.

The development of solar energy for small scale applications has already begun. Such development will certainly continue into the future. Fusion reactor development is however another story. There are many technical, psychological, economical, sociological, political, and scientific obstacles to be overcome. It is our thinking that we really have only one alternative in the long term energy development. That is to develope fusion energy sources by overcome these obstacles one by one. In order to insure smooth transition into this long range energy scenario and/or to speedup the earlier arrival of the fusion age, parallel and stronger approach for fusion research (both scientific and engineering phases) must be initiated immediately.

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THE ECONOMIC SOCIAL AND ENVIRONMENTAL IMPLICATION OF NUCLEAR ENERGY UTILIZATION IN THE PHILIPPINES

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EXTENDED ABSTRACT

According to the plans of the Philippine National Government, by 1985, the country's power source profile will look as follows: 29% hydroelectric, 32% geothermal, 26% nuclear and 13% coal, oil and others. The first nuclear plant composed of a single unit will rise up in Bataan. It will supply 620 MW of electricity and it belongs to the commercial-pressurized water reactor being exported by Westinghouse, Inc. Together with another unit, it will have a capacity of 1240 MW by 1990. To finance the project, the Philippine National Government borrowed $896.9 million from the US Export-Import Bank and it has raised a counterpart fund of ₱1.5 billion.

The plant is expected to consume as much as 10000 tons of Uranium up to the year 2000. This requirement calls for an outlay of about $70 million by 1983 and some $500 million for the remaining 15 years. The expansion program of the government regarding nuclear plants is impressive but it also raises serious questions. What are the economic implications of a developing country using a capital intensive, highly centralized and technically complicated source of electricity. Corollary to this is the question whether a poor country would be freed from the influence of OPEC. How will nuclear power affect the social structure - i.e. whether it will increase the role of the "nuclear technocrats". Finally, the environmental implication of nuclear power will be discussed.

The construction of the first nuclear plant has been started about a year ago, and then stopped by the President of the Philippines last June 1979 because of several questions whose answers were uncertain or unsatisfactory. A public hearing was conducted on the pros and cons of the nuclear plant. The main question that was raised during the public hearing was the safety aspect of the plant itself: what precautions were taken against accidents; how true is the claim that the plant is near a fault. Questions such as what to do with the nuclear wastes and where to get the uranium fuel remained unsettled.

ALTERNATIVE ENERGY SOURCES IN INDIA

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EXTENDED ABSTRACT

Professor Adelman's prediction that the OPEC cartel would collapse does not seem to be coming true! The recent sharp hike in the OPEC prices has affected both the Developed and the Developing Countries severely. Efforts are under way to find new sources of energy and also to effect economy in the use of fossil fuels, particularly oil. It is feared that the fossil fuel prices might double soon. The plight of countries like India, whose burden towards crude oil imports would increase to Rs.3000 crores due to the recent price hike, cannot even be imagined.

At present, the commercial fuels(coal, oil and electricity) contribute 56.5% of the energy requirements while the non-commercial sources supply the balance: firewood accounts for 50%, dung cakes for 25%, and agricultural wastes for about 20%. The 80 million work animals are said to be making available approximately 40 million horsepower (30,000 MW) in the country.

The installed generating capacity is about 27,000 MW and it is expected to be raised to 45,000 MW with an outlay of Rs.15,750 crores during the sixth plan (1978-83). It is hoped that alternate sources would be able to supply 2000 MW per year from 2000 A.D. onwards. Projections regarding the energy requirements upto 2000 A.D. for a population between 870 millions and 1110 millions give the following figures: coal - 650 million tonnes; oil - 97 million tonnes; electricity - 700 billion kwh(162,000 MW); firewood - 89 million tonnes; animal dung - 40 million tonnes(dry); and agricultural wastes - 46 million tonnes.

India's coal consumption is about 103 million tonnes per annum inclusive of the coal used for power generation. Its coal reserves are put at 85,000 million tonnes. The actual production of oil in 1978-79 was around 12.5 million tonnes and the import was 16.5 million tonnes. The recoverable reserves of oil in the country may be around 350 million tonnes. The hydel potential has been freshly assessed at 75,000 MW while at present only 11,000 MW have been tapped.

Out of a total outlay of Rs.71,604 crores for the sixth five year plan (1978-83), the share of energy sector is Rs.20,150 crores with its Science & Technology component getting Rs.60.63 crores. It has been realised, however, that non-commercial energy sources would play a very vital part on the Indian energy scene, specially in the rural areas. The attempts so far made and the results obtained are significant in the utilisation of solar energy and bio-gas. The National Physical Laboratory and the Bharat Heavy Electricals Limited designed indigenously and developed solar flat plate collectors. The Central Arid Zone Research Institute designed and produced solar ovens and solar cookers. Development of solar pumps for agricultural purposes is being carried out at many institutions. The Central Marine Chemicals Research Institute has set up a pilot plant that can convert 100 litres of sea or brackish water into potable water. Solar energy is being used for drying wood, for cooling houses and for refrigeration, as also for preheating of milk to make milk powder. A mobile 2-5 tonnes capacity grain drier has been developed in Tamil Nadu for use during the monsoon season. The Central Electronics Limited has developed Photo-voltaic modules for use in Remote Light Houses and radios.

Nearly 75,000 gobar plants are operating under the control of the Khadi and Village Industrics Commission in the country and Rs.70 crores have been provided for extension of this scheme during the sixth plan period. An inter-disciplinary time-bound research programme in biogas technology, sponsored by the Department of Science and Technology has been going on in eight institutions in India: this includes utilization of cowdung, night soil and agricultural wastes.

11 wells in the Puga-Chumatang area are yielding 100 tonnes of steam and water at a temperature of 140 degrees C. Geothermal energy thus produced is being utilized for refining crude borax and sulphur. A project for the development of cold storage using geothermal energy has been initiated at Manakaran in Himachal Pradesh. Future programme includes study of other areas where hot springs have been located, e.g. Parbati area, Sohna, Western India and West coast.

A National coordinated plan for utilization of wind energy is proposed to be developed. For this purpose, a Task Force is being constituted, which would examine available data and assess wind mill designs suitable for Indian consitions. At present, 50% of the wind mills in the country are located around Bangalore in Karnataka and new mills are proposed to be set up at Veraval in Gujarat. Indian Institute of Science, Bangalore has developed a water pumping wind mill.

Studies on tidal energy are being initiated. The Gulf of Cambay, the Gulf of Kutch and the Sunderban are being considered as suitable sites for tidal power generation.

A fresh long-term energy policy for the country is on the anvil in which, besides the above, energy from firewood figures prominently. The National Commission on Agriculture has recommended introduction of social forestry schemes on a wide scale. Energy plantations along the coasts and planting of eucalyptus, neem and pras grass in hilly areas are being considered. Development of Inland water transport system is being taken up to supplement the other transport means and economise fuel.

Trial runs on a limited scale have been made using ethanol in motor cars. There is a feeling that using alcohol from sugarcane might create pollution problems and also lead to social tensions. India has made much progress in the field of conversion of coal into oil. There is a proposal under consideration from an American firm which has offered to invest for conversion of 10 million tonnes of coal into 2.5 million tonnes of crude a year. A Working Group on Energy Policy has been set up to estimate the prospective energy demand, to recommend measures for optimum use of available energy resources and to outline the national energy policy for the next 15 years.

THE LIMITS OF CONSERVATION

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EXTENDED ABSTRACT

The strategy of conservation has often been suggested by many in and out of government as a partial solution to the waste, product residue pileups, and energy shortfalls plaguing industrial nations. The argument put forth rather forcefully is that Industrial Man, Americans especially, are extravagant and wasteful in the consumption of goods and services, consuming the resources of a rather tenuous earth in locust fashion. Environmentalists are fearful that the current world population explosion combined with the ravaging industrial plunder of the earth's natural resources will eventually precipitate an irreversible ecological mistake on a cosmic scale -- a mistake from which mankind could not recover.

The ecological imbalances and other problems related to high levels of consumption are serious and pose a challenge that must be met by the governments of the globe, but the strategy of conservation has serious limitations not often noted along with the statement of the world's consumption problems.

The strategy of conservation contains some inherent conflicts with social goals and objectives. First, conservation, even when reducing waste, reduces spending and consumption which tends towards recession and unemployment. World economic growth is dependent upon increasing energy consumption, not upon decreasing consumption. In short industrial energy not consumed means X amount of goods not produced.

On real and known risk of conservation is under-consumption. This risk arises out of the nature of the consumption and product exchange process itself. Reducing consumption of energy resources tends to reduce consumption of all goods and services, which in turn reduces economies of scale in production throughout an economic system. When consumption begins to drop, excess capacity begins to build up, workers are laid off from their jobs and welfare payments are increased. If an economic system operates well below capacity, say at 70 per cent, there is a real loss of goods in the upper 30 percentile of production -- a loss that can never be regained.

Industrial Man has learned that there are many economic payoffs to high levels of consumption, that is, consuming at near full capacity and full employment of the factors of production. High levels of exchange of goods for services and exchange of services for goods, facilitated by an efficient medium as money, is the key to wealth creation and secure stores of value. Exchange adds value to goods and services because it is essentially a need/supply matching process that distributes goods and services to users and consumers at points in time and space where they are needed or wanted. When consumption of potatoes drops below cost-recovery prices they rot in the

fields; when the consumption of beef drops below cost-recovery prices, farmers shoot their cattle in angry protest; and when the purchase of automobiles drops below planned levels, inventories pile up, excess capacity develops and unemployment rises. In short, industrialized economies tend to malfunction when consumption drops significantly and all people tend to lose as a result of the loss of goods and services not produced.

A conservation strategy such as rationing, for example, is limited because it interferes with the homeostatic forces of the free market and constrains the exchange process. The price mechanism itself is the best sonserver or allocator of scare resources. Price controls that set prices below the makret price also thwart the free market processes and serve to limit supplies and thus cause even greater shortfalls -- and higher prices. Conserving, as such, is not an effective response to scarcity; allocation is always the central problem of scarcity and "conservation" is best effected by a free market.

Given the current world social and economic structure, the strategy of conservation is a limited solution to global energy shortfalls. While the reported results of conservation in reducing consumption of energy has been gratifying, conservation must of necessity reach a point of diminishing returns in savings and thus not properly serve as a long term strategy of insuring adequate energy supplies.

CONSERVATION AND THE CONSUMER

Possibly the most unmanageable limitation of a conservation strategy lies in the nature of the consumer himself. The consumer has historically viewed modernization as a decrease in the level of physical human energy and labor in exchange for an increase in the energy consumed from oil and other energy sources. Conservation is frowned upon by the consumer because it runs counter to this trend by typically demanding an increase in human energy and labor in order to compensate for reduced energy consumption from other sources.

For example, carpooling does reduce gasoline consumption but it may also require workers rise earlier in the mornings, walk to a pick-up station, and give up the convenience of shopping during the noon hour. Subtracting the value of oil energy from the distribution side of the exchange equation requires the subtraction of the value of human energy from the consumer side of the exchange equation; this subtraction of value is viewed as a real loss by consumers.

Conservation is limited as an effective strategy because it typically demands that in exchange for reduced oil energy consumption the consumer must give up a quantifiable measure of value plus opportunity costs measured in social and psychological terms -- not easily quantifiable. Consumers, in the main, have always been willing to pay the market price for any energy source or device that will significantly reduce human energy output. Thus, the consumer views conservation in personal terms, in terms of conserving human energy, not other energy sources such as oil.

For example, the propensity of the consumer to conserve human energy explains the ready acceptance and immediate success of labor saving machines, appliances, and gadgets. The conumer places more value upon his human energy and effort than upon the money expenditure for labor saving devices. In addition to the value he places upon his own personal energy and effort, the consumer adds his personal opportunity costs, or the productive value of the consumer's time saved by the device. In a time-intesive world both of these components of value sum to a total value typically much higher than the cost of the labor saving machine or device. This principle, called substitution, explains the popularity of labor saving innovations in developed and developing economies.

In the consumer's mind conservation means that if he consumes less fossil duel energy he must expend more human energy -- if it means nothing more than the mental irritation and physical energy expended in turning off lights the children left on. Conservation, to the consumer, means doing without something of value he used to possess or enjoy; it means, in a very personal way, a reduction in the package of goods and services he once enjoyed.

In the consumer's mind, he never views his spending and consumption habits as wasteful. To enjoy a warm, well-lighted home in the evening is not considered wasteful by the consumer; he knows that he can turn out all the lights in the house, turn down the thermostat and put the family to bed and by so doing conserve fossil fuel energy. But he does not wish to conserve; he wants to spend. He wants to convert fossil fuel energy into forms of heat and light that modify and add value to his home. If he must reduce consumption below his comfort level he considers this a loss, not a gain, a real reduction in his standard of living. Because the consumer does not consider it wasteful to be comfortable, admonitions by government officials to conserve energy fall on many deaf ears. Admonitions to conserve may even have the reverse effect of increasing consumption rather than decreasing consumption. Large automobiles seem to sell well when consumers realize that government law and policy are phasing them out. Given the egocentric nature of the consumer, admonitions simply heighten the fear of having to five up something he values and thus intensifies the competition among consumers for scarce goods.

A government strategy of energy conservation is seriously limited in a free market economy where consumers are free to spend their incomes as they please. Given the nature of the consumer, only the force of law and the restraint of price will limit the consumption of energy. Admonitions and appeals to his civic pride are doomed to failure. When individuals enter the marketplace, they do not think of themselves as citizens, they think then primarily as consumers.

IMPLICATIONS

The central implication of the market anlaysis presented is that oil importing nations cannot rely upon conservation efforts alone to solve the problem of energy shortfalls. Government planning and policy must not encourage conservation to the point of precipitating recession or of giving up attainable growth levels. Innovation, not conservation should be the central goal.

The central implication for oil exporters is that the price for crude oil must rise in small, regular increment to encourage conservation by industrialized and developing nations but not so high that world recession occurs or that attainable world growth is not achieved. Developed nations must continue production of goods and services for relatively high levels of consumption until technological innovations can relieve the problem of energy shortfalls. Neither oil exporters nor importers must allow conservation policies to slow the solid trend of world economic growth. Consumption levels, once achieved, set the standard of living demanded by consumers; failure to maintain that standard tends toward product/service shortfalls that have serious policy implications for national and world planners.

A TIGER IN YOUR TANK? DON'T COUNT ON IT!

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ABSTRACT

This paper addresses several aspects of the alternative fuels commercialization process. These include: an overview of U.S. energy use; the concept of commercialization; the impacts of supply shortages and demand inelasticity upon commercialization; and, an assessment of alternative fuels to date.

The paper notes that the U.S. energy market is essentially numerous submarkets. The interrelationship among these submarkets precludes the need to commercialize for a specific fuel/use. However, the level of consumption, the projected growth in demand, and the inordinate dependence upon foreign fuels dictate that additional supplies be brought to the U.S. energy marketplace.

Commercialization encompasses a range of measures that are designed to accelerate the process by which technologies/products are brought to the marketplace. As discussed in this paper, such a "union" of willing buyers and willing sellers requires that three general conditions be met: product quality comparable to existing products; price competitiveness; and adequate availability of supply. Given the demand inelasticity (with respect to price) in the U.S. and abroad, supply shortages — actual or contrived — generate tremendous upward pressure on energy prices. This upward pressure allows once unattractive alternative fuels to become more price competitive. Finally, the paper treats the product quality, price competitiveness, and product availability with respect to alternative fuels commercialization efforts to date.

ENVIRONMENTAL IMPACTS TO BE CONSIDERED IN POLICY-MAKING DECISIONS FOR DEVELOPMENT OF NONCONVENTIONAL ENERGY SOURCES

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EXTENDED ABSTRACT

Currently the U.S. economy is heavily dependent on oil and natural gas. Increasingly limited availability of these sources is focusing our attention towards the development of new energy sources. In this paper we are focusing on this and are discussing the major potential environmental effects of nonconventional energy sources, those sources that have not yet developed the technology necessary to begin generating a major portion of the nation's energy.

Seven nonconventional sources are considered: geothermal, solar, wind, tide, oil shale, solid waste, and coal gasification and liquefaction. Potential environmental impacts on ambient air quality, on local surface and groundwater resources, and on land resources are discussed. Air evaluation considers major pollutants and trace elements; water analysis includes the evaluation of potential effects both on water use and contamination of the local surface and groundwater resources; and land analysis includes potential effects on existing land uses and on vegetation and animals, including man.

Although the general public and many regulatory agencies consider nonconventional energy sources "pollution free," this paper proves such a concept to be a myth. No energy source is completely pollution free. In addition to some of the impacts associated with conventional energy sources, some nonconventional sources pose some unique impacts different from those of conventional sources, while other nonconventional sources are inherently nonpolluting, the processes necessary to convert their energy into electricity do present potential impacts that cannot be ignored.

Environmentalists who believe alternative sources to be pollution free have suggested that the technological development necessary for their large-scale utilization might be speeded by massive funding, such as that made available to the Manhattan Project. They fail to recognize the impacts that would become obvious as plants for the new sources become operational and as the geographic limitations and the finite supply of each source are realized. That is, technological advances increase utilization only within unalterable limitations.

Decisions regarding policies associated with the rate of development of the different alternative energy sources must consider all aspects of these new technologies. Research and development must be conducted on a rational basis, in recognition of the limitations and the environmental consequences of a given source. Alternative energy sources open a new area of opportunity to both the environmentalist and industry, in that if potential impacts can be delineated now, they can be largely mitigated through adaptation of technology before a particular source becomes commercially available.

Future efforts in developing alternative sources must not only seek to fulfill growing energy demands, but must simultaneously recognize that in substituting nonconventional for conventional sources, the environmental consequences of exchanging one impact for another must be avoided.

SESSION 5A

HEAT STORAGE AND TRANSFER II

TROMBE-MICHEL WALL USING PHASE CHANGE MATERIAL

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EXTENDED ABSTRACT

INTRODUCTION

Use of massive masonry walls (collectors) for short term thermal storage in passive systems has been proposed and investigated by Trombe and Michel[1] and others[2,3]. Their findings show that this concept offers a considerable amount of solar energy gain without some of the drawbacks of the active systems. For the time being the disadvantages of this approach are the overheating of the inner surface and large weight walls that increase construction expenses. The almost constant temperature operation of the phase change materials (PCM) and their high energy density suggest their possible use in similar configurations without some of the drawbacks of the masonry systems as mentioned above. A schematic of this concept is shown in Fig. 1. An approximate, theoretical analysis of this PCM wall unit is developed in the following sections. The results indicate that substantial amount of the heating load can be met by utilizing these passive elements.

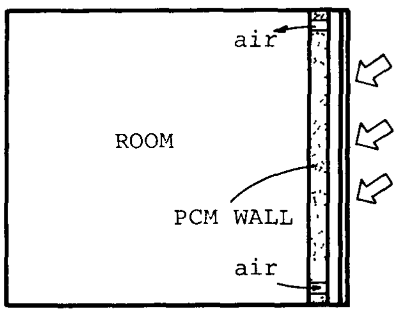

Figure 1. Trombe-Michel wall of PCM type.

ANALYSIS

A computer model was developed to predict the performance for the Trombe-Michel wall of PCM type installed in a building. The PCM wall acts essentially as a flat-plate solar collector and thermal storage unit with double glazing. Air is used as the heat transfer medium.

The simulation is carried over a 24 hour period during which the usefulness of the PCM wall in night-time home heating is investigated. The unit is envisioned in the south facing vertical wall of the Solar One, the experimental solar house of the

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††Assistant Professor

University of Delaware. The direct gain through the windows along with auxiliary heating meet the heating demand during the day and the PCM wall with auxiliary heating meet the heating demand during the night. In day-time operation, the PCM wall is exposed to direct insolation. The solar intensity incident on the surface is simulated by a curve fitting technique using the observed data. The amount of heat stored in the PCM wall and the position of the melt front is determined by a fully explicit numerical technique[4]. Considering the geometry of the PCM wall and the flow conditions, a one dimensional approach to the phase change problem was considered to be adequate. The method employed is capable of taking into account the time dependent heat flux boundary condition during the charging period, when the unit melts using the solar heat. At night-time, room air is blown through the PCM wall and the glazing so that the heat stored during the day is removed and delivered to the room. This discharge process results in the solidification of the PCM. It is possible that the amounts of the stored and extracted heats are not equal; in this case sandwiched layers of solid and liquid phases will appear. The numerical technique used to solve the phase change problem was improved such that a region having multiple solid-liquid interfaces could be analysed. A uniform convective heat transfer coefficient during the discharge is assumed. The heat loss from the PCM wall to outside is calculated by considering the temperature difference and the heat loss coefficient between the exposed PCM wall surface and the ambient air. The insolation on the east wall in the morning and on the west wall during the afternoon are also considered in the analysis. A sinusoidally varying ambient air temperature is assumed over a 24 hour period.

The thermal exchanges among the structural elements of the house, the room air and the various heat sources (viz. direct solar gain, PCM contribution, auxiliary heat) and the heat losses are modeled by considering them in two lumped systems as

$$(\rho c_p V)_w \frac{dT_w}{dt} = A_{w_1} \alpha_w I_1 + A_{w_2} \alpha_w I_2 + A_i h_i (T_i - T_w) + A_o h_o (T_o - T_w)$$

$$(\rho c_p V)_i \frac{dT_i}{dt} = A_{wi} \tau_{wi} I_1 + \dot{Q}_{PCM\ wall} + \dot{Q}_{aux} + A_i h_i (T_w - T_i) + A_{wi} U_{wi} (T_o - T_i)$$

Here, $\dot{Q}_{PCM}$ is obtained from the solution of the phase change problem and the equations above are solved numerically.

RESULTS

The predicted performance of the PCM wall for the Solar One is presented in Fig. 2. The analysis was made by considering the data for a Na_2SO_4 (Glauber's Salt) mixture as the PCM and using the weather information for a mid February day. It was estimated that over a 24 hour period 21% of the total heat load can be supplied by the PCM wall under clear weather conditions comprising about 25% of the south facing wall.

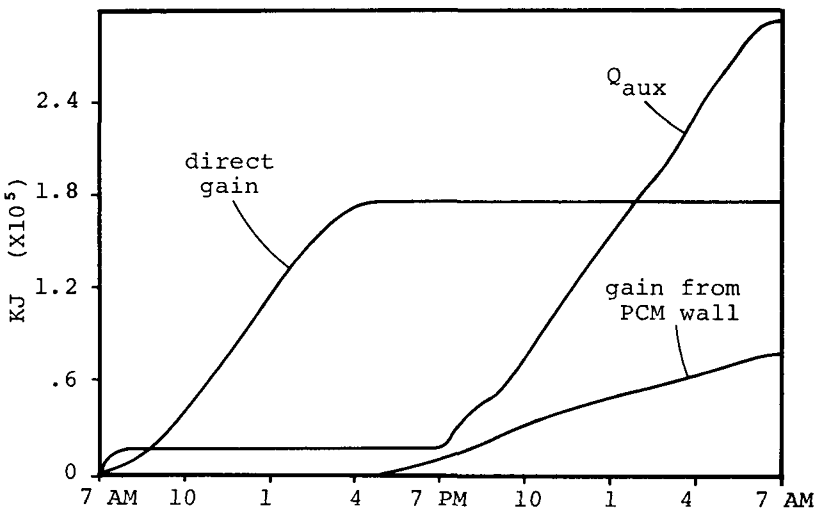

Figure 2. Performance of the PCM wall for Solar One in a mid February day.

NOMENCLATURE

A	area	α	absorbtivity
I	insolation	τ	transmissivity
h	convective heat transfer coef.	ρ	density
T	temperature	V	volume
t	time	c_p	specific heat
$\dot{Q}$	heat flow		

Subscripts:

1	south facing walls	w	structural wall
2	east or west facing walls	wi	window
o	ambient air	i	inside thermal mass

REFERENCES

References will be furnished in the proceedings and upon request.

MEMBRANE-LINED THERMAL STORAGE SYSTEMS

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EXTENDED ABSTACT

INTRODUCTION

Membrane-lined liquid thermal storage containers promise lower costs and easier installation than conventional steel or fiberglass tanks. A project to investigate and further develop this concept was begun in May, 1978, at the University of Nebraska-Lincoln and funded by the Research and Development Branch, Office of Conservation and Solar Applications, United States Department of Energy.

Steel tanks are currently the most common storage containers for solar heated water. The membrane-lined storage alternative being investigated and further developed in this project has the following potential advantages compared to steel tanks:

Reduced Corrosion Problems Without a steel storage tank, no dissimilar metals need be used in liquid based solar heating systems.

More Convenient Construction Scheduling The storage tank components easily fit through doorways, and may be installed at any time in the construction process, with excellent applicability to "retrofit" projects.

Improved Heat Transfer Configurations Easy access to the tank interior permits location of free-convection heat exchangers within the container, eliminating pumps, external heat exchangers, and some parasitic power consumption. Some membrane-lined designs facilitate forced air heating from the storage surface area.

Cost Reduction For residential solar space heating systems, membrane-lined storage containers may generally be completed for less than one-third the cost of steel tanks. The savings result partially from integration of the storage container into the building foundation. For example, the storage structure may be constructed in a basement corner, where only two new walls need be added.

The project is designed to assess the current state of development of membrane-lined storage, develop optimized enclosure designs, and develop designs which improve storage heat transfer and temperature stratification. These objectives are being pursued via the following three project activity lines:

Activity 1 includes a survey of completed membrane-lined storage projects, a review of alternative membrane materials, and identification of the most cost-effective membrane enclosures for a range of building foundation types, for storage volumes of 250, 1500, and 5000 gallons. Most of this work is now complete, and the results are summarized in the paper.

Figure 1 shows projected storage cost curves for basement installation. The cost models include the installed, insulated storage enclosure, without piping, but including contractor's overhead and profit.

Activity 2 involves development work aimed at improving heat transfer to and from storage, including:

2a) Techniques for direct heat transfer from the storage surface to forced air, with laboratory testing of several promising design concepts and cost-effectiveness studies based on test results. Figure 2 is a section view of a cylindrical container using the direct air heating concept.

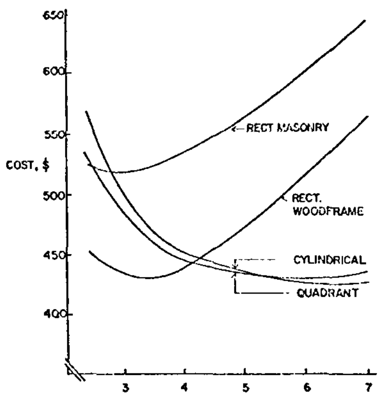

Figure 1 1500 Gallon Basement Storage Enclosure Cost

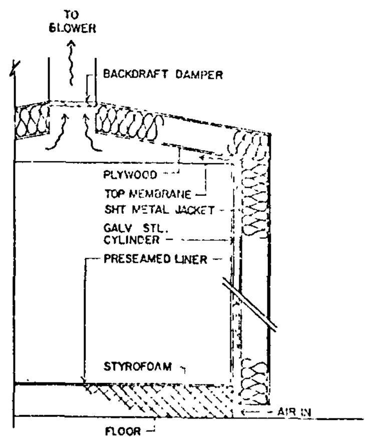

Figure 2 Storage Surface-to-Air Heating

2b) Techniques and details for water inlet to and outlet from membrane-lined storage containers.

2c) Comparison of alternative free-convection heat exchangers for pre-heating of domestic water, with laboratory testing of the preferred designs and cost-effectiveness studies (Figure 3) based on the test results.

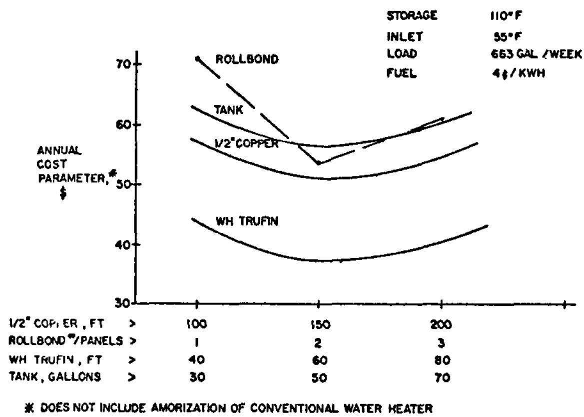

Figure 3 Domestic Water Preheater Cost-Effectivness

2d) Concepts for input of auxiliary heat to storage, for application where utilities offer rate incentives for off-peak energy consumption.

Most of this work is now complete, and results are described in the paper.

Activity 3 involves designs which promote storage temperature stratification to improve overall system performance, including multiple tank designs (3a) and baffled tank designs (3b) with development of cost models and small-scale testing of promising designs. Much of the work remains to be done. Results will be described in a future paper.

Full scale construction and testing of these designs should occur in 1980.

PASSIVE DESIGN METHODOLOGY

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EXTENDED ABSTRACT

The present waste of energy resources in the built environment is only symptomatic of cultural attitudes which have lead to intense industrialization and massive consumption of available stocks of energy resources. These cultural attitudes are based on the assumption that the environment is a free good in infinite supply. Post-Industrial Revolution societies have been built on these non-factual premises.

Every ecosystem has the capacity to absorb a specific amount of energy utilization. This energy utilization can consist of the gathering of food, the dispersion of pollutants, or the consumption of elements of the ecosphere--such as forests or minerals. This capacity to absorb energy utilization is called the carrying capacity of the ecosphere. Modern industrial societies ignore the reality of the limited carrying capacity of both their local environment and the global ecosystem.

Passive environmental design is based on the premise that environments can be designed in such a way as to produce human comfort and perform tasks by utilizing only income energy resources. The utilization of these resources will not produce the same impacts on the carrying capacity of the ecosphere.

The wealth of industrial societies has consisted of the ability to rapidly exploit existing concentrations of high quality energy and natural resources. This form of wealth is limited by both the relatively small quantities of such resources and the carrying capacity of the ecosphere. Real environmental wealth for a society consists in the match between its activities and the steady state supply of income energy resources.

It is the author's belief that a passive social evolution involving appropriate technology based on indigenous materials is the key to a steady state economy. In such an economy the society always restricts its use of energy resources to a level which is within the boundaries of the carrying capacity of the local environment and the ecosphere. The elements of this passive solar evolution are illustrated in Figure 1.

Architectural practice must develop buildings and cities which nourish this passive evolution. This is particularly true of rural environments in developing countries. These societies cannot afford to imitate the consumption patterns and problems of the industrial world. They need examples of ecologically sound uses of income energy resources. Passive solar design is one such example.

The application of solar energy to human needs involves more than technological issues. This paper analyzes solar design in terms of sociological variables, environmental variables, and technical variables. A passive solar designer must seek to develop the four major societal and individual characteristics: spiritual, mental, emotional, and physical values. The integration of these characteristics within society and the individual can lead to a rational program of passive solar evolution.

The environmental and physical variables involved in passive solar design are outlined in Figure 2. This methodology is concerned with both macro-analysis and micro-analysis. Macro-analysis focuses on form, space and system. Micro-analysis focuses on geometrical, thermophysical, and operational criteria (1). We conclude that "form does not follow function", rather "form follows climate and nature in support of function".

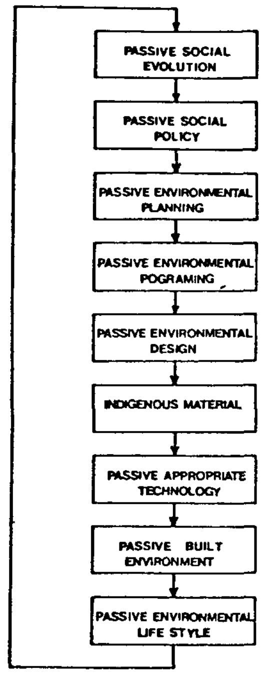

Fig. 1 - Passive Solar Evolution

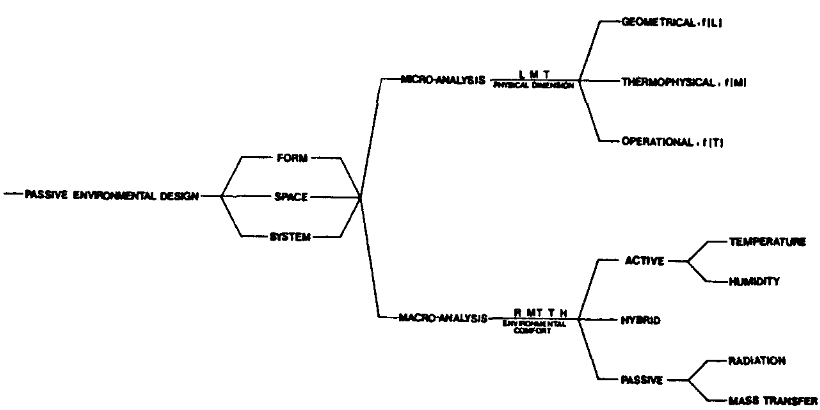

Fig. 2 - Passive Environmental Design

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HIGH TEMPERATURE STORAGE FOR A WIND ENERGY SYSTEM

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INTRODUCTION

The system is designed to use wind energy to provide "topup" energy for a home heating system. Electric power is generated by a wind turbine generator and converted to heat in a high temperature storage unit which supplies the specified load.

Operating curves of a commercial Darrieux wind turbine and generator are used in the simulation from which a transfer function is derived. It relates the electrical heat energy to the wind speed input. The output heat energy is directed only to the storage from which the load energy is partially derived.

HIGH TEMPERATURE STORAGE

The high temperature storage facilitates the use of high energy density storage. The thermal energy is maintained as high grade heat enabling it to be used as a power or spaceheating source.

A conventional unit consists of a rectangular shaped refractory brick core placed in a high temperature insulating jacket. The core is heated to a maximum temperature of 700°C by electric elements in the core and heat is extracted by forced air through ducts in the core. To reduce the case loss high grade thermal insulations are used and both the air inlet and outlet are placed at the base of the unit to prevent convective currents.

The core design consists of vertical air passages and horizontal passages for the heating elements. These passages are formed when the specially shaped bricks are placed together.

The core material provides the limiting factor in design. For high temperature storage refractory materials are the most suitable. Metals such as aluminum and iron have superior thermal qualities but suffer from higher cost and oxidation.

The heating elements are of 80/20 nickel chrome alloy wire which is formed into an open wire spiral and placed in the element passages. The dominant heat transfer mechanism is by radiation. Due to the high temperatures a high grade of alloy is required. To prevent overheating each element has a safety thermal link.

The core design does not have the capability of supplying an external heating load during the core charging period. An auxiliary electric heating element is required to supply energy during the core charging cycle. During the core discharge cycle the available output power decreases as the core cools. However, a new design for a packed bed overcomes both of these problems.

Packed beds, which comprise containers filled with pebbles, have been used to store thermal energy at temperatures below 100°C. This study involves the use of packed beds at temperatures in excess of 600°C. The design procedure for a packed bed involves the compromise between small size pebbles for good heat transfer and large size pebbles for low air flow pressure drop. Once the size has been determined it becomes standard for units of all energy and power ratings.

A characteristic of the evenly distributed vertical air flow is a low temperature thermal wave travelling up the bed during the discharge cycle. This signifies high power output independent of the energy stored because of the rapid heat transfer to the air from the lower layers of the bed. Consequently the cross-sectional area of the bed determines power output. Once power output is fixed the height of the bed is determined by the specified energy to be stored.

A grid structure is used to support the bed and provide uniform air flow. The strength of such a steel structure would be lowered at temperatures exceeding 482°C. Because of the thermal wave pattern, the structure can be maintained at a relatively low temperature by having the air flow downwards for charging the unit with energy and reversing the air flow for discharge.

Heating elements in the core are not suitable because of the movement caused by thermal expansion and contraction. Heating elements outside the core have the advantage that the core temperature can then exceed 700°C. This simplifies construction and servicing also.

The manufacturing cost of the pebble core material is considerably less than that of special shaped bricks. The construction of the core and elements are simple compared to conventional brick cores which are built up by placing alternate rows of bricks and elements.

SYSTEM DESIGN

Design procedures for both conventional storage core units and packed bed storage units are developed in detail in the main paper. The design procedures comprise of sections concerning elements, core materials, input-output characteristics and insulation.

The turbine and generator may be optimally sized for the requirement of a maximum aggregate of the generated wind energy. The integration is computed for the heating season for various values of turbine diameter and generator size. A summary of the results is presented in Fig. 1. From these results a practical per unit turbine size and generator size may be selected for a particular load.

The purpose of storage is to absorb excess energy during the period of integration and supply the load when the turbine output is low. Given the wind and temperature data a suboptimization may be performed to match the turbine generator unit with the storage to the load. The storage is sized to provide the required load power except for one or two percent of the time when short term extreme conditions exist.

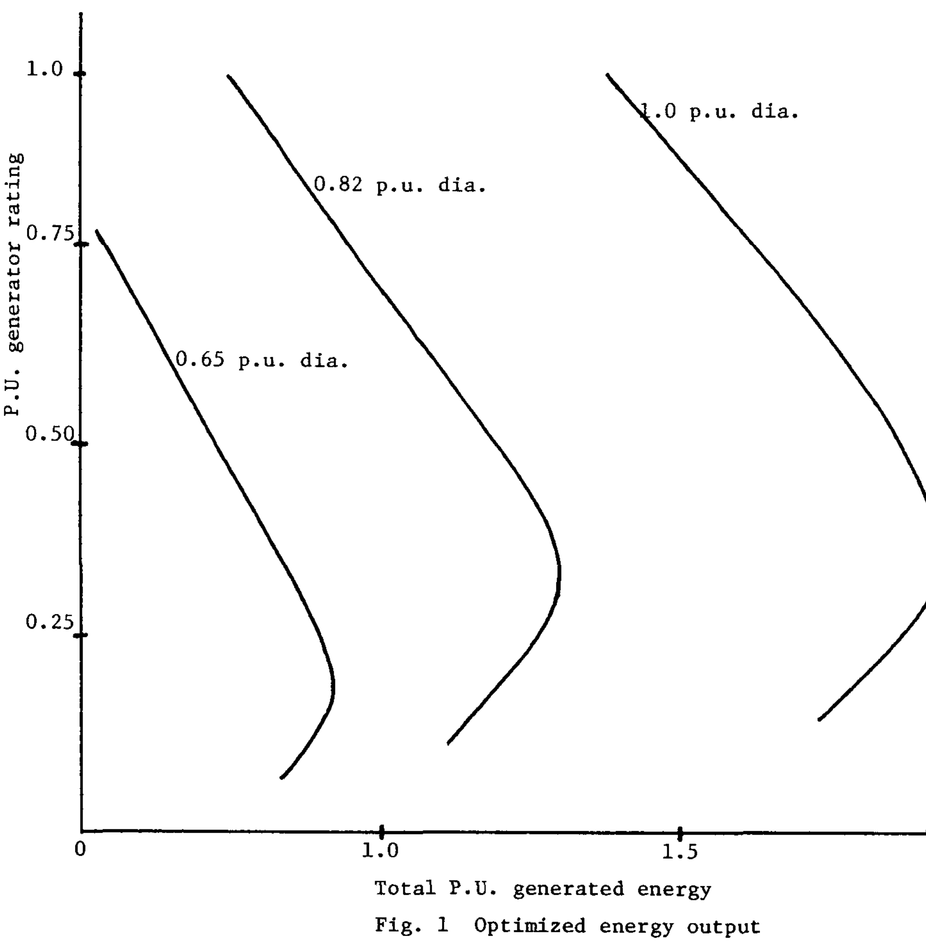

Fig. 1 Optimized energy output

HEAT TRANSFER THROUGH A PARAFFIN-WAX SOLAR-ENERGY-STORAGE, CHARACTERIZED BY A TEMPERATURE-DEPENDENT SPECIFIC HEAT

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EXTENDED ABSTRACT

INTRODUCTION

The numerical solution of heat transfer equations describing the melting process of a phase-change material (PCM) has been studied by many authors. They deal generally with pure materials presenting a well-defined solid-liquid transition at a precise melting temperature. This work presents a method of resolution used to simulate the experimental results obtained with industrial paraffin-W-axes. These PCMs are mixtures of various saturated hydrocarbons, so that the latent-heat effect appears on a large temperature range (8°C or more) as a quickly varying specific heat. This model involves both conductive and radiative heat transfer in the medium and realistic boundary conditions describing the heat losses towards the ambiance. The accuracy of the method is checked on the basis of experimental results, and conclusions on the dynamics of thermal storage in such a medium are presented.

PHYSICAL PROPERTIES OF PARAFFIN WAXES

Paraffin waxes are of great interest for solar heat storage systems, because their use is very easy (no corrosion) and their melting-solidification cycles extremely stable. The experimented paraffin is an industrial 50-52 paraffin (melting range around 50-58°C, latent heat of about 160 J/g). This material is constituted by more than 90% of n-paraffin. The DSC analysis gives a curve of heat capacity versus temperature that presents an important peak from 50 to 60°C, corresponding to the fusion latent heat and a secondary peak from 28°C to 36°C indicating a previous solid-solid transition. The thermal conductivity of the medium varies from 0.3 W/m°C at the ambiant temperature to 0.2 W/m°C at 60°C. The density is 0.775 in the liquid phase and 0.860 in the solid phase out of the transition zone. In the visible spectrum, white paraffin presents a high global reflexivity, due to diffusion, in the solid state and the liquid is semi-transparent. When used by direct exposition to solar radiation, paraffin waxes must be coloured in order for the global absorption to be increased on one hand and for the transmission of direct radiation in the liquid phase to be maintained at a good level on the other hand: this has been shown to help the poor conductive heat transfer due to the low thermal conductivity.

RESOLUTION OF HEAT TRANSFER EQUATIONS

In this study, we consider an horizontal slab of red-coloured 50-52 paraffin receiving a normal solar radiation flow through a double glazing. The usual one-dimensional conduction equation includes a radiation transmission term in the liquid phase. The analytical expression of this term has been deduced from the experimental curve. Besides, the equation is kept in its general form, where both ρC_p and k (thermal conductivity) are temperature dependent. Radiative and convective exchanges with the ambient air are represented in the boundary conditions by linearized constant coefficients. The residual radiation flow, inside in paraffin, is assumed to be entirely absorbed in the liquid-solid interface.

The set of equations is solved by an iterative finite difference scheme using the Crank-Nicholson method of discretization. The computation gives the temperature distribution in the slab (space step : 0.125 cm) at every time step (1 minute). The position of the liquid-solid separation is deduced from the position of the 49° C isotherm (experimentally verified).

COMPARISON WITH THE EXPERIMENTAL RESULTS

The computational model is checked with an experimental device : an horizontal slab of paraffin-wax is exposed through a double glazing to the vertical radiation beam of a solar simulator (constant intensity : 600 W/m^2) during a eight-hour period. The temperatures measured at various levels of the slab are compared with the results of the program (processed on UNIVAC 1110) and very good agreement is obtained for the following values :

- global normal absorptivity of the paraffin surface, $\alpha = 0.70$
- bottom exchange coefficient : $h_F = 2.5\ W/m^2{}^\circ C$
- upper heat loss coefficient : $h_S = 2\ W/m^2{}^\circ C$ when solid phase above
  $h_S = 3.5\ W/m^2{}^\circ C$ when liquid phase above.

CONCLUSIONS

The experimental results show that the progression of the liquid solid interface is linear for a constant value of the radiation flow. This is verified in the numerical results.
Integrating the specific heat capacity between initial and final temperatures for every space step of the slab, it is possible to know the power stored in every level of the system and in the whole system. The total energy stored during any period of time and the corresponding storage efficiency of the system can also be deduced.
The analysis of the results allows us to describe with great precision the heat propagation process in a strongly temperature-dependent heat-capacity system. This model can be used to simulate any working conditions for the paraffin and to study the effect of the time fluctuations of the incident radiation flow.

THE USE OF CONCRETE BLOCK DIRECTLY UNDER A CONCRETE SLAB AS A HEAT STORAGE SYSTEM IN A PASSIVE SOLAR HEATED BUILDING.

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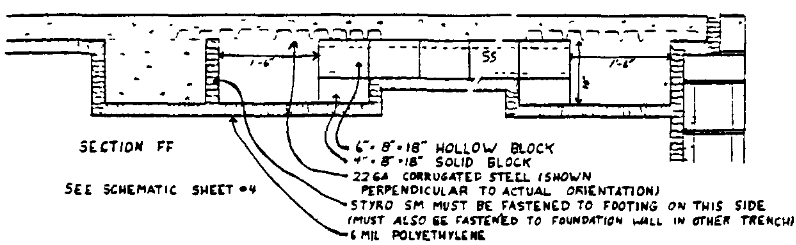
EXTENDED ABSTRACT

In direct gain systems, concrete floors have their storage potential limited by their effective thickness and by the limited area that is irradicated at any one time. As the slab surface heats up, a great deal of heat is given over to the air above the slab and removed from primary storage. This results in room temperature swings that exceed those generally accepted by a society used to conventional thermostate ranges of 3° F, as well as an increased envelope loss due to elevated interior temperatures.

A system is described with the dwelling treated as a stratification tower whereby air heated at the irradiated surfaces rises to the high point of a 23 foot vertical space. Directly beneath the floor slab is an area of 6 inch concrete blocks creating north, south passageways that are fed and relieved by east, west subfloor headers. A differential thermostat has sensors in the storage mass and at the high point of the stratification tower and triggers a 600 CFM fan that draws the heated air from the tower down to the floor storage. See accompanying drawings.



The advantages of the system are:

1. Elimination of living space overheating in many situations.

2. Release of heat from storage for a greater time period after sundown.

3. More uniform distribution of heat in the slabs Northern portion.

4. Reduction of heat loss from the living space due to elimination of high temperature excursions.

The Lornell House is located in the Albany, New York area (6880° days), and had a total backup heat need for the 1978-79 season of 35 MMBTU (27 MMBTU of gas for $82 and 8 MMBTU wood via one cord of mixed soft wood burned in a box stove). The performance of this system was hampered by the following conditions:

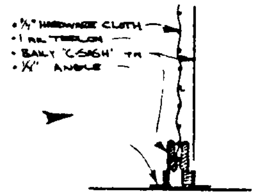
1. 39 percent reduction in percent of possible sunshine in January.

2. 25 percent reduction in percent of possible sunshine in March.

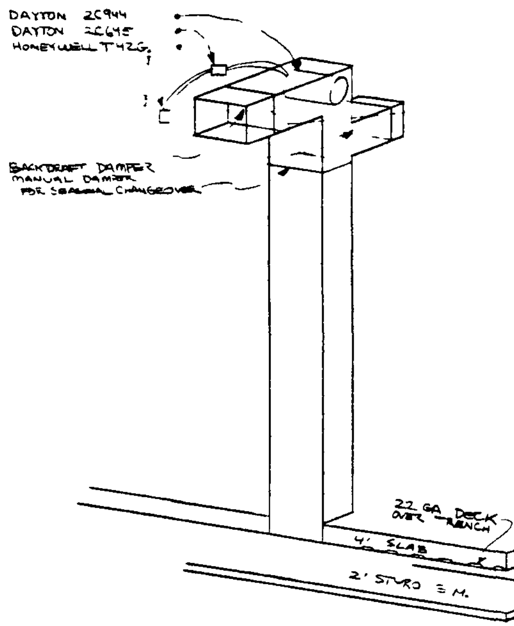
3. Late start up of heat storage system resulting in an investment of an undetermined large number of BTU to heat the soil mass adjacent to storage.

4. Absence of thermal shutters on 25% of the windows.

Required storage mass is sized according to the following procedure. For the months of Oct., Nov., March and April, solar gain and daytime heat loss are calculated for the structure. The resultant excess heat gain is quantified for average and high gain conditions ("clear sky"). After subtracting the mass capacity of the dwelling over 7° temperature swing, the resultant storage requirement is determined. The capacity of the storage system is about 16 BTU/°F/sq. ft. Judgements are made on a somewhat arbitrary basis regarding what amount of overheating will be allowed, and how much energy will be dumped.



BACKDRAFT DAMPER DETAIL
FULL SCALE



HEAT STORAGE SCHEMATIC
NO SCALE

THERMAL STORAGE CELL FOR HIGH TEMPERATURE SOLAR SYSTEMS

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EXTENDED ABSTRACT

INTRODUCTION

Solar generated electricity as a sole source of utility power is feasible both economically and as a stable, constant power supply if adequate storage can be provided at a cost which is competitive with other power generation systems. For comparison, an Onan 70 kW gas-driven generator will cost $9000 plus installation, and will generate 5.8 kilowatt hours for each gallon of fuel consumed.

In 20 years of operation, the generator will provide 6,132,000 kWh at an average duty factor of 50 per cent, and consume 1,051,000 gallons of fuel at a 1980 cost of $1.00 per gallon. Thus the cost of operation for 20 years, neglecting maintenance, will be $1,060,000, or 17 cents per kilowatt hour if fuel prices do not increase.

A solar thermal electric system with storage, of the same deliverable power, will cost about $350,000, and again neglecting maintenance, that is the cost of 20 years operation; a third that of the fossil fuel generator, or 6 cents per kWh.

Maintenance costs for the gas-driven system will be substantially higher than for the solar system, since the solar system uses no oil, oil filters, fuel filters, ignition parts, air filters, etc., which must be changed frequently; and a vapor engine is less costly to overhaul than the gas-fueled engine.

The solar system is superior in every respect if it can provide continuous power throughout the year, regardless of weather conditions. This can be accomplished with suitable storage.

Storage In order to be effective in the most severe climate, the storage system must meet several criteria. It must:
1. Store a minimum of one week's power;
2. Recharge in 10 to 12 hours;

3. Have a minimum 10-year life since it represents 50 per cent of total system cost;
4. Be simple and maintenance-free.

Since 5 to 6 hours of solar radiation should be expected in a one-week period in any season between the 45° latitudes; and since net conversion efficiencies of 33 per cent are average; a storage cell capable of absorbing energy at many times its average rate of discharge is needed. Therefore, the cell must be highly conductive. For example, a cell of 2000 kilowatt hours deliverable capacity should be capable of receiving 500 kilowatts instantaneous input during charging. Such a cell will service 10 average homes for one week of sunless weather.

An example which illustrates the storage concept graphically is a steam engine which requires 600°F steam for operation. 600°F then is the minimum temperature which should be maintained in the cell. If the upper temperature limit is 1800°F, then an effective storage range of 1200°F is possible. Assuming that the storage medium within the cell will store .12 Btu per pound, per degree F, and also assuming that this medium weighs 50,000 pounds, then at 1800°F we have stored 1200°F X 50,000 pounds X .12 = 7,200,000 Btu, or 7,200,000 ÷ 3414 = 2109 kWh. If we can extract the stored energy at 33 per cent efficiency, then 696 kilowatt hours of electricity are available for use.

The storage medium considered here is highly alloyed steel. Steel shot of 2 cm diameter has a surface area of 12.56 cm^2. 51,800 pounds of this shot would be equivalent to a steel plate 1 cm thick and 817 square meters in area. This amount of shot will fit into a cubical container 2 meters on a side.

Due to the spherical shape of the shot, it will settle into the container in a uniform way, and the surface area and void area will be uniform throughout the cell. Consequently, the thermal gradients within the cell will be uniform, effecting rapid energy transport throughout the storage medium. The charge-discharge rate for the cell can be as high as 140.7 X 10^6 Btu/min., giving the cell the needed recharge capability.

Application To construct the system, a vault is excavated in the earth and lined with ureathane foam. A concrete vault is poured inside the foam liner, sand is poured into the bottom of this vault, the storage cell placed inside, and a lining of sand then fills the space between the walls of the cell and the concrete vault. This method insulates the storage cell and provides safe containment.

In a typical system, a 2000 kWh cell would require 75 tons of shot. With a 500 kW instantaneous input and 12.6 hours of direct sunlight, 21.6 million Btu will be stored in the cell. Thirty-three per cent efficient vapor engine/generator sets can convert this 21.6 million Btu of thermal energy into 2080 kilowatt hours of electricity at any rate desired. The average home consumes 27 kWh per day; therefore, the energy stored within the cell can supply 77 homes for one day, 10 homes for 8 days, etc., without recharging. In a sunny climate, this system can service 25 or more homes continuously, and the system capacity can be scaled-up almost without limit. The 2000 kWh cell would be 2.6 meters on a side in cube form, and represents a storage density of 114 kWh per cubic meter, deliverable energy.

Utility Applications In large scale applications, a 10-acre field of mirrors, in the greatest possible density, will collect 35 megawatts of solar energy at 80 per cent efficiency, with a resulting 6-hour delivered energy storage capacity, at 33 per cent recovery, of 69,000 kWh. This capacity would serve 365 homes in a climate with only 6 hours of direct solar radiation per week, or 2500 homes in an area of 6 hours of direct radiation per day, with deliverable storage of 485,000 kWh, and as the system is scaled upward, the cost per delivered kWh drops significantly. The 10-acre installation, with one week's storage, can deliver continuous power to 2000 homes in the south central United States at a 20-year amortized cost, including maintenance, of 5 cents per kWh.

In the same area, to serve a city of 100,000 population, or 30,000 homes plus 600 attendent businesses, it would require 200 acres of land, an installed cost with 20 years maintenance of $260,000,000; and would realize an annual net profit of one million dollars. Consumer cost would be 3.7 cents per kWh.

These figures are based on homes and industries with an average electrical consumption of 900 kWh per month; a utility plant site at the edge of the city; a city with a mean diameter of 10 miles; and 30 hours of direct sunlight per week. The utility company would employ 50 persons at an average wage of $10.00 per hour including employee benefits. Services and lines are calculated at $4000 per customer installation.

In the next 20 years, no other form of fossil or nuclear fueled power generation will be able to compete economically with solar thermal electric power generation if the latter is put into wide scale use.

A NEW FORMAL GRAPHIC LANGUAGE FOR THE REPRESENTATION OF COMPLEX ENERGY DISTRIBUTION SYSTEMS

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In northern countries so called multi-component heating systems are increasingly used because at present no economic way for seasonal energy storage is known. These multi-component heating systems are combinations of solar collectors, heat storage tanks of relatively low capacity, heat pumps, and conventional stand by heaters. For their graphic representation installation schemes are commonly used which show all details necessary for the definite installation work. These installation schemes are, however, perfectly inadequate - since too complex - for a clear system philosophy representation.

To overcome these problems, a new graphic language for the representation of heat distribution and storage systems is introduced and demonstrated on two examples. This language follows closely the so-called "Network of Instances and Channels (NIC)" representation form used in information theory for the description of complex computer systems. The only significant difference is the change in symbol interpretation. While the computer science speaks e.g. of data channels we talk of energy flows.

After getting familiar with this energy path graph representation form one can use this both clear and rigorous description language as powerful tool for system design and analysis as well as for measuring data interpretation. It allows for a quick change of the appropriate abstraction level and helps for judging the relative merits of alternative configurations. Although this graphic language is demonstrated for heating systems only, it may also be utilized for the description of most general energy distribution systems.

SESSION 5B

SOLAR HEATING AND COOLING III

ANALYSIS OF SOLAR-POWERED ABSORPTION CYCLE HEAT PUMPS WITH INTERNAL/EXTERNAL ENERGY STORAGES

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EXTENDED ABSTRACT

This paper presents the results of a study of solar-powered heat pumps based on a water-lithium bromide absorption refrigeration cycle. Such systems offer an opportunity to use solar energy to produce a cooling effect and the possibility of multiplying the heating effect of solar energy. Solar-powered absorption cycle cooling systems have been demonstrated experimentally[1] and have been applied in residential and institutional buildings[2]. This study is concerned with

1. Understanding the operational characteristics of solar-powered absorption cycle heat pumps.
2. Developing operational algorithms to optimize system operation.
3. Presenting parameter study results in terms of solar energy utilization and system cost.

System diagrams and performance equations are presented for solar-powered absorption cycle heat pump systems utilizing two different modes of energy storage. In the first system a flat plate collector is coupled to the absorption cycle generator through a thermal storage external to the other elements of the system. This is the external thermal storage (ETS) system. In this system, a cooling load demand is satisfied by a call for operation of the absorption cycle generator either on energy from storage or on auxiliary energy to supply the necessary refrigerant.

The second system has the flat plate collector coupled directly to the absorption cycle generator and has three latent energy storages internal to the cycle itself. This is the internal latent energy storage (ILES) system. A system diagram of the ILES system is presented in Figure 1. The ILES system satisfies a cooling load demand by supplying refrigerant from the internal refrigerant storage tank. The three storage tanks act to separate the system in two sections - 1) the collector, generator, and condenser; and 2) the evaporator, absorber, and cooling load demand. Each section operates relatively independent of the other, leading to greater operational flexibility and higher solar energy utilization for the ILES system[3].

Discrete time computer models of the two systems are developed to enable operational and parameter studies to be carried out. Generalized weather functions are used to represent insolation and building load demands to the systems. Analytical expressions are developed to represent H_2O-LiBr absorption cycle operating temperature limits.

Results from computer studies using the models disclose dual state points for the ETS system in terms of energy supply rate, q_G, and absorption cycle generator operating temperature, T_G[4]. Figure 2 shows the determination of the operating (or state) points of the ETS system at a given instant in time as the intersections of the non-linear characteristic operating curve of the absorption cycle with the linear curve that describes the energy withdrawal from storage. Operating algorithms to minimize auxiliary energy requirements are developed and described for the ETS system. Control of the storage-to-generator flow rate is used to avoid the crystallization temperature limit and also to achieve peak system efficiency.

All collected solar energy is utilized in the ILES system to generate stored refrigerant by means of control of refrigerant-absorbent mixture flow to the generator. An operational algorithm to maximize the production of refrigerant as a function of solar intensity is developed and incorporated in the ILES system model. This algorithm is demonstrated in Figure 3 where refrigerant production rate, w_C, and collected solar energy, q_{col}, are plotted against generator temperature, T_G, as the flow rate of weak absorbent, w_{WA}, to the generator is varied. The curve of w_C vs T_G in the figure shows that control of w_{WA} can maximize the production of refrigerant for a given solar intensity. Operating algorithms that cope with emptying tank situations by either the introduction of auxiliary energy or the rerouting of other stored fluids are also developed and demonstrated.

Parameter studies are performed for the systems that show system performance as a function of storage size (both absolute and relative) and also as a function of the ratio of peak load demand to peak intercepted radiation. Comparisons between the ETS and ILES systems show that the greater capital cost of the ILES system is offset by lower auxiliary energy requirements.

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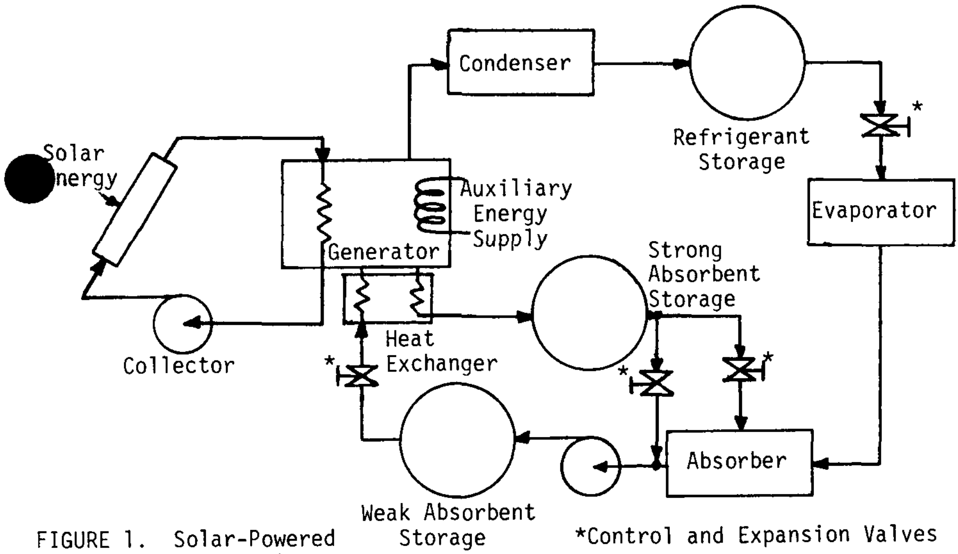

FIGURE 1. Solar-Powered ILES Absorption Cycle Heat Pump System

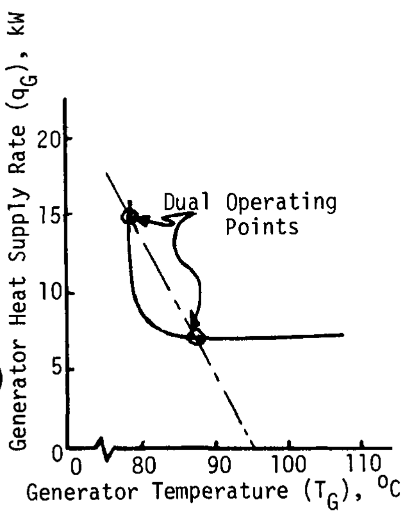

FIGURE 2. ETS Operating Point Determination

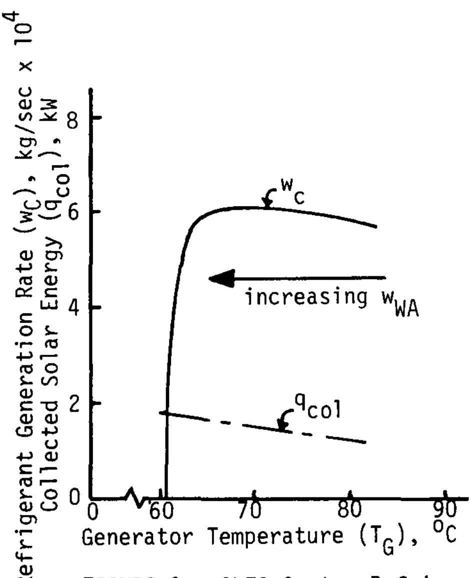

FIGURE 3. ILES System Refrigerant Flow Maximization

SOLAR-POWERED SALINE SORBENT-SOLUTION HEAT PUMP/STORAGE SYSTEM

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EXTENDED ABSTRACT

Coastal Energy Laboratory Chemical HEAt Pump (CEL-CHEAP) is a redesigned open-cycle liquid desiccant air conditioner. Heat is discharged to shallow-well water by dehumidification-humidification for cooling and extracted by humidification-dehumidification for heating. Direct solar radiation concentrates the desiccant. For continiuous operation, a small uninsulated tank stores concentrated solution.

This chemical heat pump [1] needs no mechanical compressor, vaccum system, or pressure system. The collector-regenerators are inexpensive. The refrigerant is water and the desiccant is calcium chloride. First cost and operating expenses are very low.

The U.S.C. open-cycle desiccant air conditioner [2] has been redesigned to include a heating cycle by replacing the triethlene glycol sorbent solution with calcium chloride solution.

A collector-regenerator is being used to obtain data to verify the design paramenters.

During the cooling cycle, warm, humid, outside air is continuously cooled by shallow well-water and dehumidified by a concentrated saline sorbent solution. Both sensible and latent heat are removed. The dry process-air is then further cooled to a temperature lower than the well-water temperature by humidifcation with cool water. Sensible heat is converted to latent heat. After picking up the room heat-load, the process air flows out through the collector-regenerator (area = 1 m^2/3.5 KW = 100 ft^2/ton) and carries away the moisture from the hot, dilute desiccant solution, which has been heated by direct solar radiation as the solution flows through the collector-regenerator. Sensible heat absorbed by the liquid and not used for mass transfer is recovered by a heat exchanger.

During the heating cycle, cool, room air is heated and humidified as it flows through the collector-regenerator across the hot, dilute sorbent solution. The air gains both sensible and latent heat (latent heat/sensible heat = 2.5). The warm, wet air then flows through the conditioner. With the cooling water cut off, dehumidification by the warm concentrated salt solution further heats the air to a temperature higher than the collector temperature. Latent heat is converted to sensible heat. This process allows efficient operation of the collector at a low temperature.

Storage of the concentrated solution [3] is at ambient temperature during the cooling cycle. During the heating cycle, storage is at room temperature. Diurnal or seasonal energy storage is possible with energy density as high as 2.5 MJ/L (2,500 BTU/gal) of saline solution.

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METHOD OF TESTING FOR PERFORMANCE RATING OF SOLAR WATER HEATING SYSTEMS

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EXTENDED ABSTRACT

INTRODUCTION

A basic procedure is outlined for testing solar domestic water heating systems which would operate in the following modes:

a) Solar only or solar preheating
b) Solar-plus-conventional heater integrated into the same storage tank

The testing procedure which is presented here describes the use of solar radiation and system evaluation in practically occurring or specified day-to-day operating conditions. The testing of thermal performance is executed during the system steady-state operation and could be performed during a short (few days) or a long (a year) period of time during the system durability and reliability testing.

1. PERFORMANCE EVALUATION

The four factors considered essential for the performance evaluation of solar water heating systems and which subsequently should be evaluated during system performance measurement are:

a) Solar energy collected per unit collector area
b) Solar fraction of total hot water load
c) Conventional energy saved by the solar energy system
d) Solar hot water system conversion efficiency

Other parameters such as: solar energy utilized for storage hot water heating; hot water load; collector plate's heat exchange effectiveness; average solar hot water load temperature; average amount of solar hot water consumed, could also be evaluated during the testing.

1.1 Solar Energy Collected-Per Unit Collector Area The amount of solar energy collected per unit collector area in a given time period is determined as follows:

$$Q_c = \frac{1}{A_c} \int_{\tau_1}^{\tau_2} M_c \quad C_{pc} \quad \underbrace{(T_{out} - T_{in})}_{\Delta T_c} \quad d\tau \qquad (1)$$

where

A_c = the total collector area defined by the outside dimensions of transparent frontal area of the collector array

M_c = the collector array fluid mass flow rate

C_{pc} = the specific heat of collector fluid

ΔT_c = the fluid temperature increase across the collcetor array

1.2 Solar Fraction of Hot Water Load The solar fraction of the hot water load is calculated as follows:

$$f = \frac{1}{\Delta\tau} \int_{\tau_2}^{\tau_1} \frac{\Delta T_s}{(\Delta T_s + \Delta T_{aux})} d\tau \qquad (2)$$

where

$\Delta\tau = \tau_2 - \tau_1$

and assuming that there is a flow to the hot water load ($\dot{M}_s = \dot{M}_L \neq 0$) and that $C_{ps} = C_{pL}$.

or

$$f = \frac{Q_{Load} - Q_{Aux}}{Q_{Load}} \qquad (3)$$

where

Q_{aux} = the auxiliary energy used in the auxiliary water tank

Q_L = the hot water load

ΔT_{aux} = the fluid temperature change across the auxiliary tank

1.3 Conventional Energy Saved by the Solar Energy System The conventional (electrical or fossil) energy saved is calculated as the difference between the measured value of energy consumed by the non-solar system Q_C and the measured value of energy consumed by the solar system Q_S. Equipment performance based on seasonal efficiency rather than design point efficiency should be used.

$$Q_c = \frac{Q_L}{\eta} \qquad (4)$$

where

η = the conversion efficiency of convensional energy into the thermal energy (η_e = 0.78 - 1.0; η_f = 0.5 - 0.6) and

$$Q = Q_c - Q_s \quad (5)$$

1.4 Solar Hot Water System Conversion Efficiency The ratio of total solar energy actually utilized to the total solar energy incident on the collector array is termed the solar hot water system conversion efficiency. The solar hot water system conversions efficiency is calculated as follows:

$$N_{conv} = \int_{\tau_1}^{\tau_2} Q_{su} \, d\tau / A_c \int_{\tau_1}^{\tau_2} I \, d\tau \quad (6)$$

where

Q_{su} = the instantaneous values of the solar energy utilized

A_c = the total area of the collector array

I = the instantaneous values of incident total solar radiation in the plane of the collector array

Because of the solar energy storage time dependence, the solar hot water system conversions efficiency should be determined only for the monthly, seasonal and annual data summary.

Figures 1 and 2 show an example of sensor locations in two different solar hot water heating systems. The paper will discuss in detail the testing procedure and it will discuss the recommended instrumentation accuracy and the measurement frequency.

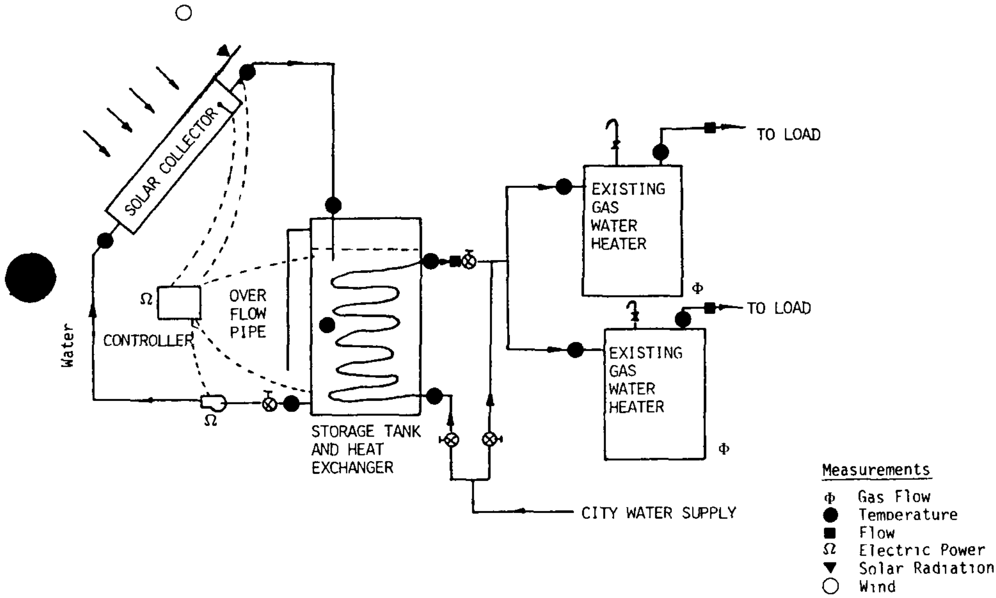

Figure 1. Sensors Locations in a Liquid Type Solar Water Heating System.

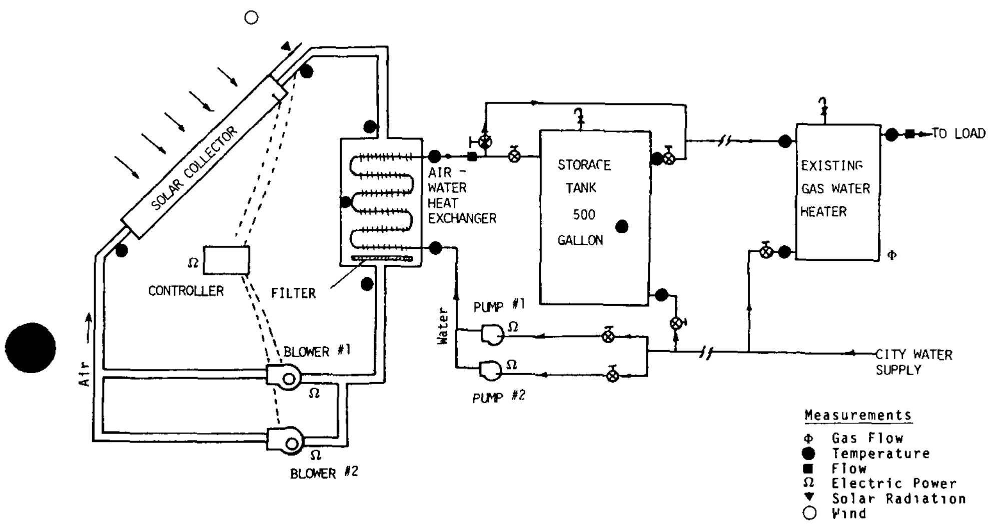

Figure 2. Sensors Locations in an Air Type Solar Water Heating Systems.

SOLAR WATER HEATING DEMONSTRATION PROGRAM FOR PUBLIC SCHOOLS IN NEW MEXICO

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EXTENDED ABSTRACT

The New Mexico solar water heating demonstration program has in view the installation of solar water heating systems in public schools in the state over a period of several years. The objective of this program is to demonstrate to the general public through legislative action and the program implementation, the economical, educational, environmental, and social aspects of the use of solar energy.

The program was initiated in 1978 by the legislative appropriation of $50,000 to design, install, and operate two solar water heating systems in high schools in New Mexico. To cover the difference between the appropriation and the installed systems cost, New Mexico Solar Energy Institute provided $2,225. The selection of schools was done on the basis of numerous criteria, the most important of which were yearly cost of water heating in the school, type of fuel source used to heat water, year-round hot water use, amount of hot water used, availability of meteorological data, availability of solar system maintenance, use of roof or ground mounted collectors, distance between collectors and storage, energy conservation practices of the school, possibility of separate metering of hot water and space heating, accessibility of the solar system to the general public, number of people in the town, number of students in the school, problem of vandalism in the school, and the matching funds contributed by the school.

Information pertaining to the above criteria was obtained on the basis of a questionnaire. Thirteen schools were selected to be considered for the program. Out of these thirteen schools two, Socorro High School and Springer High School, were finally chosen as the most suitable for the first year pilot demonstration. General information about the sites and the solar systems is presented in Table I.

TABLE I. GENERAL DATA ABOUT SOCORRO AND SPRINGER SOLAR DEMONSTRATION

Socorro Solar Demonstration	Springer Solar Demonstration
Latitude: 34°North	Latitude: 36.38°North
Elevation: 1400m (4,594ft)	Elevation: 1797m (5,896ft)
Nr. of People in Town: ~ 7,000	Nr. of people in Town: ~16,000
Nr. of Students in School: ~ 640	Nr. of Students in School: ~ 300
Solar System Load: 7.09×10^8 Joules/day (6.72×10^5 Btu/day); 4542 liters/day (1200gal/day)	Solar System Load: 6.33×10^8 Joules/day (6.00×10^5 Btu/day); 3785 liters/day (1000gal/day)
Solar Fraction: 45% of Av. Load	Solar Fraction: 55% of Av. Load
Solar System Location: on Roof of School Cafeteria and Gymnasium	Solar System Location: on Ground (50 yards from School Building)
Collector Type: Flat-Plate Water Collector	Collector Type: Flat-Plate Air Collector
Collector Area: $50.83m^2$ ($547ft^2$)	Collector Area: $99.03m^2$ ($1066ft^2$)
Installed System Cost: $28,000	Installed System Cost: $24,225
Installation Date: Dec. 1978	Installation Date: Dec. 1978
Contractor: A to Z Construction and Plumbing, Las Cruces, New Mexico.	Contractor: Alternative Energy Resources, Inc., El Paso, Texas

The contractors for both systems were selected through a bidding process. Figures 1 and 2 show a general view of the installed solar system in Socorro and Springer respectively.

The paper will discuss in detail the technical, economical, educational, and social aspects of the program.

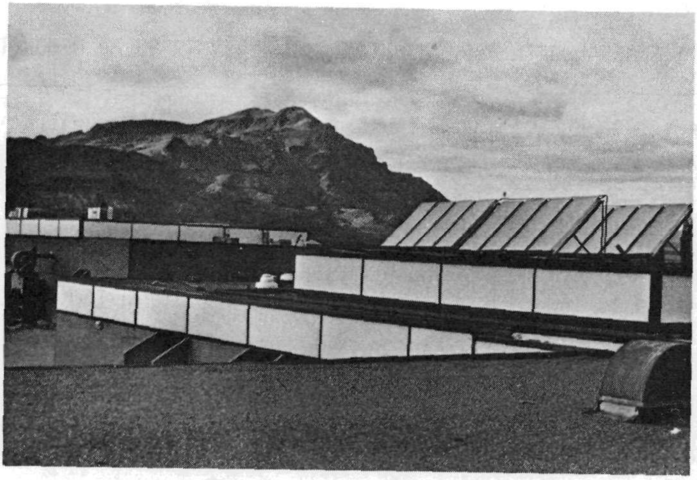

Figure 1. General View of Socorro High School Solar Demonstration System.

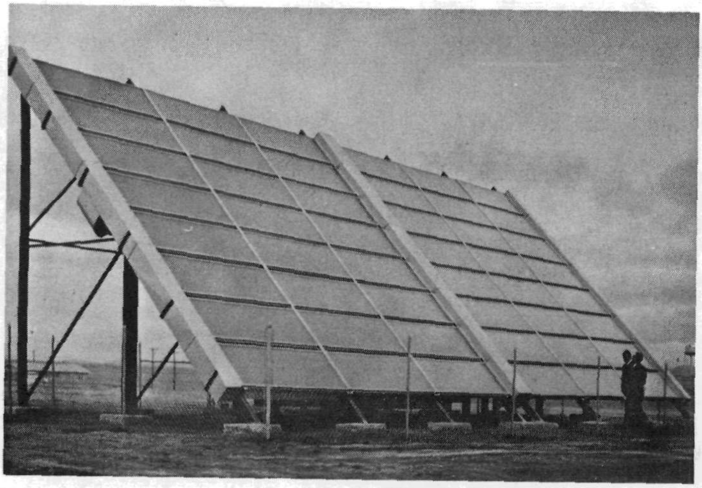

Figure 2. General View of Springer High School Solar Demonstration System

COMPARATIVE TESTING FOR THERMAL PERFORMANCE OF WATER HEATING SYSTEMS BY USING AIR AND LIQUID TYPE FLAT PLATE COLLECTORS

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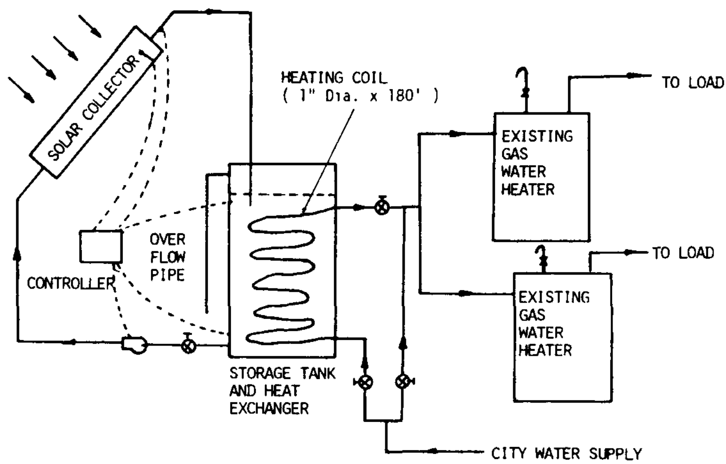
EXTENDED ABSTRACT

The purpose of this study is to evaluate the on-site thermal performance of two solar hot water systems. Socorro, New Mexico, and Springer, New Mexico, where the systems are located, represent different climatic zones. Socorro is located about 34 degrees North and Springer is about 36.38 degrees North; Springer's elevation is about 396 m (1300 ft) higher than that of Socorro. Both solar water heating systems were designed and installed in public high schools. Each system will generate averagely 0.61 x 10^9 Joules/day (600,000 Btu/day), supplying about 3785 liters (1000 gallons) of solar heated water per day. The solar hot water demonstration project in Socorro is using a drain-down system with flat-plate water collectors mounted on the roof of the school building; half the size of the collectors array is located on the roof of the school cafeteria and the other half is located on the roof of the school gymnasium. The solar hot water system in Springer is using flat plate air collectors which are mounted on the ground. Figures 1 and 2 present schematics of the solar water heating systems installed in Socorro High School and Springer High School respectively.

A standardized instrumentation system for collecting and analyzing data from these two solar hot water systems was set up. This instrumentation package is a portable type with removable sensors so it can be used at other solar sites operated by New Mexico Solar Energy Institute in the state. It consists of the Solar Energy Data Collection System on Sites (SEDCS) and a Solar Data Center (SDC). These two data gathering and processing units are coupled by a dial-up telephone system. The SEDCS acquires all necessary information such as: insolation, temperatures, pressures, wind speeds, etc. and stores it in its data storage system.

The SEDCSs are installed with solar hot water systems. The SEDCS can be controlled and monitored locally or through the Solar Data Center which is located at New Mexico Solar Energy Institute. The SEDCS data is being processed by the Solar Data Center's computer. The schematic block diagram of the Solar Energy Data Collection System is shown in Figure 3.

The paper will present and discuss in detail the thermal performance data processed so far by SDC. Conclusions will be drawn concerning the suitability of the discussed solar systems for the climate zones in which they are operating.



DESIGN LOAD	672,000 BTU/DAY (1200 GALLON/DAY, 45% OF AVERAGE LOAD)
COLLECTOR USED	FLAT PLATE WATER COLLECTOR (547.2 SQUARE FEET TOTAL)
SYSTEM LOCATION	ON THE ROOFS OF THE SCHOOL CAFETERIA AND GYMNASIUM (TWO SEPARATE SYSTEMS)

Figure 1. Schematic of Socorro High School Solar Hot Water Demonstration System.

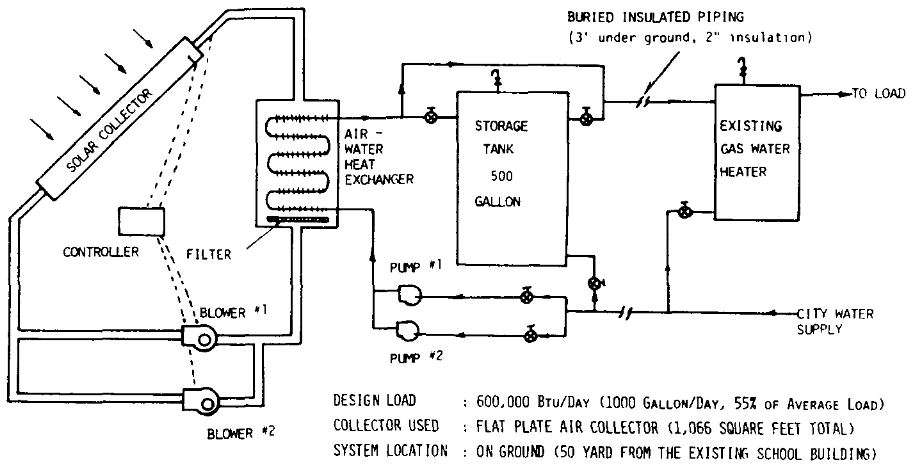


Figure 2. Schematic of Springer High School Solar Hot Water Demonstration System.

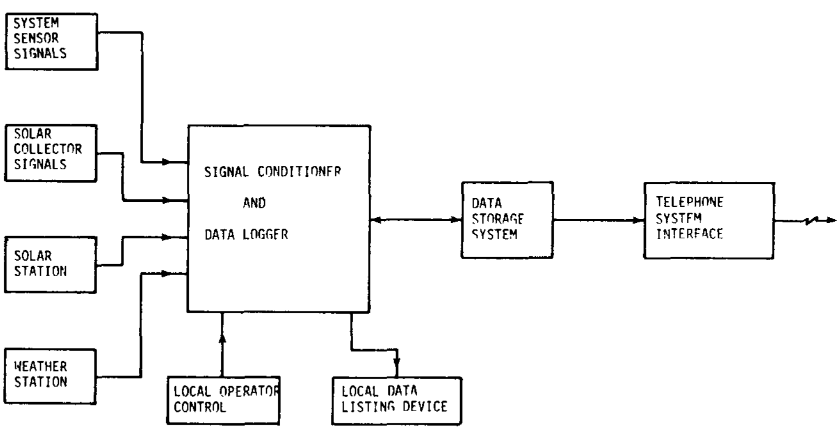


Figure 3. Block Diagram of Solar Energy Data Collection System (SEDCS).

TO MARKET, TO MARKET - EXPERIENCE IN SOLAR DESIGN FOR MASS PRODUCTION HOUSING

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ABSTRACT

The efforts of a moderately-large building form to design and refine a solar radiant floor slab heating and nocturnal cooling system are described. Cost-efficient installation and operation are basic to the system. The design process towards these goals is described from inception to final sale and service. This central California developer's privately funded, self-motivated work in innovative solar design is aimmed at the mid-priced housing marketplace. Five pairs of homes, each with progressively more sophisticated architectural and mechanical design, define the cronology of the refinement process. The culmination is large-scale solar home and apartment construction utilizing the final system design. The firm intends to profitably market a practical solar package for their buildings and those of other developers. Many problems were encountered. Among them were material and labor costs and availablities, component breakdowns, and poor performance. The resolution of these problems, yielding a simple, saleable mass-production solar heating/cooling system, is described at length.

STATE OF NEBRASKA SOLAR HEAT PILOT PROJECT - EXPERIMENTAL RESULTS - FEASIBILITY STUDIES

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ABSTRACT

This paper describes the origin, construction, and initial operating performance of the State of Nebraska Solar Heat Pilot Project. Commissioned by the Nebraska Legislature in the 1977 session, the project is designed to assess the feasibility of using alternative energy sources "for the production of supplemental hot water or supplemental building heat in other state owned structures".

Solar energy was chosen as the most appropriate alternate energy source, and the Mabel Lee Hall physical education facility (on the UNL campus) was selected for installation of a "retrofit" solar domestic water heating system. Solar collectors for the project were constructed on the ground northeast of the building. For performance comparison, two equally sized collector systems were constructed with identical enclosures and a shared underground storage reservoir.

The project went into full operation on March 21, 1978, and despite occasional operating problems, maintained a thermal storage temperature adequate for shower water throughout the reporting period ending October 31, 1978. In addition to supplying heated water to the building, the project has provided valuable information on the performance, operation, and maintenance of solar heating systems, and on hot water usage patterns in a major physical education facility.

A computer simulation incorporating operating results from the two collectors was used to compare the cost-effectiveness of 12 system design variations over a wide range of sizes, applied to the same domestic water heating load. The simulation results show that the Pilot Project is not cost-effective with assumed future fuel costs, but that improved designs suggest favorable cost-effectiveness when carefully sized and incorporated into new building structures. The best of the design variations shows only marginal cost-effectiveness when installed on existing buildings.

SOLAR HEATING AND COOLING TECHNOLOGIES - HOW CAN THEY BE INTERFACED WITH EXISTING CONVENTIONAL ENERGY NETWORKS?

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ABSTRACT

Solar heating and cooling (SHAC) technologies have been systematically designed and constructed to optimize cost-effectiveness for the individual consumer. Long-term thermal SHAC performance is optimized with respect to system and alternative energy costs. The SHAC systems are therefore normally sized to minimize cost for long-term average loads--it is the auxiliary system which is sized to handle (extreme weather) design loads. Where auxiliary energy is provided by an electric or gas utility, the auxiliary system design load may have significant impact on the utility's peak load, thus producing a technological mismatch. It is important for firms which develop SHAC technologies to recognize these impacts and to develop lower impact SHAC designs. The utility industry can be a partner in the process by providing appropriate incentives and disincentives via tariff design and other load management strategies. An optimal solution to the problem would result from cooperation between utilities and SHAC development firms.

SHAC designs which utilize utility supplied auxiliary energy and which spike utility peak loads result in high costs for the utility and for the energy consumer. This problem is especially critical for electric utilities. Utility capacity must be maintained on reserve to serve SHAC consumers during extreme weather conditions; at other times the capacity may remain idle. Poor load factors result, which reflect inefficiency in the use of capacity and financial resources.

There are three fundamental avenues by which these problems can be solved--technical compensation, legislation and standards, and economic incentives. The technical avenue would promote R and D of SHAC designs which minimize the technological mismatch. This can be accomplished by altering the sizing of SHAC components so that design condition loads are reduced. Increments in collector area or storage, or their improved efficiency would accomplish this. Several studies have demonstrated that the impact on utility peak load is strongly related to component sizing. It has also been shown that certain types of passive SHAC designs which utilize thermal mass for direct solar heat gain reduce the peak load requirements.

Legislation and standards would permit implementation of state building codes or action by Public Utility Commissions to require SHAC performance to meet some standard for utility peak load use. One way which this may be accomplished is by requiring insulation and other construction standards which serve to reduce design loads.

A third avenue would provide incentives for the consumer to adopt SHAC designs which minimize the technological mismatch. For example, solar tax credits should provide greater incentives for favorable SHAC designs as society would benefit from lower utility capacity reserves. Additional incentives would be provided by utilities which offer load management tariffs and load control discounts to SHAC customers. Such actions would benefit the utility and also the SHAC customers via reduced auxiliary energy costs.

These issues have been developed in case studies around the country, for utilities with widely varying characteristics. Commonalities between case studies emerge for winter-peaking and summer-peaking utilities. Some of the conclusions reached are that solar water heating may have a relatively benign impact on utilities; passive SHAC designs tend to require less peak load capacity than active SHAC designs; and various utility tariffs may have a large impact on promoting different SHAC designs.

SESSION 5C

OCEAN ENERGY

A BOTTOM FIXED OTEC PLANT

ON THE EDGE OF A CONTINENTAL (OR ISLAND) SHELF

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EXTENDED ABSTRACT

For the past five years, the original concept of generating electrical energy from the vast thermal resource existing in the temperature gradient between the warm surface and the deep cold waters of tropical oceans has been subjected to extensive studies in the United States as well as in Europe and Japan. Various alternatives for the power cycle (open or closed), for the working fluid (ammonia, water, freon, etc.) and for the plant deployment site (offshore floating or land-based) have been considered.

With the floating offshore platform type OTEC plants, significant technological problems such as the structural dynamics of cold water pipe, and the difficulties with the platform station Keeping System and the electrical transmission cables, still remain to be resolved. As a possible alternative, a land based OTEC plant has been studied [1] Although this type of plant avoids some of the problems of a floating offshore platform, it has some other unique problems. It requires longer cold water pipes to reach the ocean depths where the favorable temperature gradient exists; the diameter of the cold water pipe has to be larger to account for the additional friction losses; and the pumping power must be increased due to these added pressure losses. Also, the plant itself will probably require prime waterfront property and may result in disturbing coral reefs in many of the coastal areas suitable for OTEC plant construction.

The idea of a bottom fixed OTEC platform appears worthy of consideration for these reasons. A bottom fixed plant attempts to reach a compromise between the floating offshore and the land based plants by eliminating the cold water pipe structural dynamics problems, the station keeping requirements, and the need to shut down operations under severe hurricane conditions.

One possible application of a deep water bottom fixed OTEC plant was described in a paper presented to the 6th OTEC conference in June 1979 [2] . This is basically a guyed tower type platform, and according to the author, "can be built and installed, and it would have superior life and station keeping ability". For some of the potential

OTEC sites, designated by the U.S. Department of Energy, such a platform may indeed be the optimum answer; for example in three of the five potential OTEC sites, the desirable temperature differential occurs at great distances away from the shore and the continental shelf extends further away from the shore as compared to other sites.

Two of the potential sites, i.e. Hawaii and Puerto Rico, have rather short island shelves. The site in Puerto Rico, for example, is off Punta Tuna in the south east coast of the island. The shelf here extends to approximately 6000 ft. from the shore and the the depth increases with a very steep slope so that the desired temperature gradient is not far from the shelf edge. A bottom fixed OTEC platform positioned on or near the edge of the continental (or island) shelf at such a site will provide additional advantages and will represent a more state of the art design, construction, and deployment approach in that instead of the 3500 to 4000 ft depths, one now has to deploy the platform in much shallower water (150 to 200 ft).

This paper presents the results of a qualitative and conceptual evaluation of probable platform types for deployment in shallow water on the edge of the shelf.

The alternatives considered are primarily configurations that have different locations for the OTEC powercycle components and different platform types. It is found that a centralization of the OTEC power cycle equipment on the platform is the best option and that the platform configurations can vary as shown in Table 1.

The paper discusses these alternative concepts along with their application to OTEC sites in Hawaii and Puerto Rico. The study of applicability for Puerto Rico is in more detail, including construction, power grid integration, and environmental considerations.

It is concluded that a bottom-fixed OTEC plant located at or near the edge of the continental or island shelf, in the relatively shallow waters prevailing at such locations, appears to be a very promising option which can greatly accelerate the commercialization of the ocean thermal energy conversion concept because:

- o The platform/containment vessel for such an OTEC plant is state-of-the-art.
- o The need for extensive design efforts and the possible extension of the state-of-the-art technology for station keeping systems is eliminated.
- o The need for extensive research, testing, and eventual production of electrical riser and underwater transmission cables is eliminated since this OTEC plant can use existing cables.
- o The cold water, warm water, and combined discharge pipes to be used in connection with this plant are not subject to the very large hydrodynamic forces acting on a pipe attached to a floating platform.

TABLE 1. ALTERNATIVE CONFIGURATIONS FOR THE CENTRALIZED PLANT

ALTERNATIVE NO.	BASIC CONFIGURATION	DESCRIPTION
1	Bottom Fixed - Above Surface	Uses a conventional jack-up type platform. - Condenser only located at ocean bottom. CWP ties directly to Condenser. - All other systems located on the jack-up. - Warm water pipe extends down to mixed layer from platform.
2	Bottom Fixed - Above Surface	Uses a truss type tower with all systems located on the above surface structure. Legs of the tower are used as ducts to bring cold water up to the platform.
3	Bottom Fixed - Submerged	Uses a gravity type platform, such as the CONDEEP for example, with all plant systems within the submerged portion of the platform and all accommodations within the above surface structure.
4	Bottom Fixed - Submerged	Uses a separate submerged power barge for all plant systems, a separate warm water intake tower, and a separate tower structure with above surface accommodations.

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COUPLING OCEAN THERMAL ENERGY CONVERSION TECHNOLOGY (OTEC) WITH NUCLEAR POWER PLANTS

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EXTENDED ABSTRACT

INTRODUCTION

Until recently major industries have forgone the most efficient uses of energy on economic grounds; however, the continued rise of fuel costs along with increasing shortages of supply is beginning to change this argument.
It has been suggested that a low boiling fluid could be employed in Rankine cycle systems for a variety of energy saving purposes, i.e., from the utilization of waste heat [1] to the improvements of high temperature gas reactor efficiency [2].

The use of organic working fluids allows recovery of the maximum amount of energy practical. From a low temperature source this is because of the low heat of vaporization of the organic working fluid relative to water, which permits the organic cycle to operate under nearly thermodynamic reversible conditions [3].

The modern fossil fuel plant produces steam at 1,000°F and 3,000 psi, however, safety considerations hold the current LWR to 600°F and about 1,000 psi for the BWR and 2,000 psi for PWR [3]. Therefore nuclear power reactors may be ideal condidates for efficiency improvement of this type.

CONCEPT FOR OTEC TYPE BOTTOMING CYCLES

In this paper we suggest a method of improving the efficiency of LWRs by means of a binary cycle which utilizes deep ocean water in a manner similar to OTEC. This work examines the potential thermodynamic improvement obtained by coupling an OTEC type bottoming cycle to both fossil and nuclear plants. And then compares these with potential thermodynamic improvements using surfac water.

To take advantage of this OTEC type bottoming cycle a plant must not only be located near a large water source but also must be close to deep cold water. This would restrict the number of sites where such a technique could be applied. Coupling OTEC Technology to Floating Nuclear Power Plants or Nuclear Power Park [as described by Murata [4]] of course, minimizes the cost of the cold water pipe.

Calculations were performed for a large Floating Nuclear Power Park in the temperature waters of Japan.

CONCLUSIONS

These advantages of using deep cooling water are discussed and in some cases compared to standard OTEC systems, e.g. the size of heat exchangers and the diameter of the cold water pipe would be [illegible] smaller than for a typical OTEC system.

Costs associated with a BINARY-OTEC type bottoming cycle are likely to be much lower than those of standard OTEC plants due to the smaller size components required and the potential for sharing some components with the rest of the power plants. With a BINARY-OTEC bottoming cycle, the nutrient rich water can be raised to a sufficiently high temperature to assure that it will stay near the surface enabling the plankton to utilize these nutrients. This may help to increase the productivity of mariculture systems.

One big advantage over using surface cooling water is the almost complete elimination of adverse themal pollution effects even from systems as large as 10,000 MWe. Results indicate an increase of electrical output of up to 10% for nuclear, and 6% for fossil plants using BINARY systems with A (deep water)-OTEC bottoming cycle.

On the other hand only about 5% and 3% increases were obtained using surface water, respectively. Cost estimates are not given, because uncertainties in nuclear safety and licensing considerations, make meaningful estimate infeasible at this time. In conclusion we recommend a BINARY cycle research and development effort for improvement of LWR efficiencies, however, it may be prudent to initiate these efforts with fossil system because of the complex reactor safety issue involved.

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DESIGN OF OTEC SEACOAST TEST FACILITY AT KEAHOLE PT., ISLAND OF HAWAII

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EXTENDED ABSTRACT

Ocean Thermal Energy Conversion (OTEC) as an energy source is still at an embryo stage. Wideranging theoretical and experimental studies have been produced for the Department of Energy by many consultants and scientists. Heretofore there has been limited opportunity for actual hands-on long term experience with the critical problems of biofouling, corrosion and heat exchanger performance, and almost no testing using deep ocean water. This situation is now changing. Recently at Keahole Point, on the big island of Hawaii, the MINI-OTEC Project became the first installation to produce net electric power using ocean thermal energy. Also, to be located in the same general area, two other OTEC research projects OTEC-1 and the OTEC Seacoast Test Facility are at an advanced stage of design. Unlike MINI-OTEC and the OTEC-1 Project (a test facility to be constructed on the converted Navy Tanker "Chepachet"). The Seacoast Test Facility (STF) is, as its name implies, to be a shore-based OTEC laboratory. The final design of this unique facility is the subject of this paper.

Under contract with the Argonne National Laboratory, the Research Corporation of the University of Hawaii selected the engineering firm of Parsons Brinckerhoff to first prepare conceptual designs and then final designs, plans, specifications and bidding documents for the STF. This facility, also to be situated at Ke-ahole Point on the Big Island of Hawaii, will provide an ideal environment for the long term studies needed to evaluate OTEC equipment components and power cycle configurations.

A land-based facility has some basic important advantages over floating OTEC laboratories. The primary advantage is the assurance of uninterrupted experiments during severe storm conditions. The nature of many of the OTEC experimental programs require that they be operated for months or years at a time. Interruption of pumping could destroy the continuity of such experiments and require that they be started over at great cost and loss of time. Access and comfort of personnel, ease in delivery of units to be tested and room for expansion of laboratories are some other important advantages.

Some of the Seacoast Test Facility design criteria reveal the unusual and innovative nature of this project:

- Intake Depths: Warm Water 50 feet
  Cold Water 2100 feet

- Minimum Intake and Discharge Flows:
  Warm Water 9600 gpm
  Cold Water 6400 gpm

- Uninterrupted flow for both warm and cold water.

- Cold water temperature rise (from 2100 ft. depth to test area) not to exceed 1°C.

- Provision for degassing the cold water intake ahead of pumps.

- Pipeline materials to be biologically inert and not introduce corrosion product contamination.

- Cold water must be discharged at a depth of not less than 180 ft.

- 100 year design storm: 30 Ft. significant waves.

- System Design Life to be ten years minimum.

Some of the most significant design challenges involve: (1) The requirement for a water intake to be installed to the record depth of 2100 ft. (inaccessible to divers) on an underwater mountainside and operated continuously for a design life of 10 years: (2) The criteria for biologically inert pipeline materials which dictated the use of a polyethylene pipeline; (3) The unusual hydraulics of this mile-long intake line; (4) Anticipated currents and storm wave conditions with peak wave heights of over 50 ft. (5) Budget constraints which precluded the use of heavy petroleum industry pipelaying barges normally used for laying pipelines in deep water.

This paper will provide a comprehensive description of the proposed OTEC Seacoast Test Facility and the design rationale for the deep cold water intake pipeline, the nearshore and onshore pipeline protection, the warm and cold water supply and discharge systems, the onshore laboratories and service facilities and planning for the incorporation of future energy related programs. Environmental studies and constraints will also be outlined. Finally, a brief description of the currently planned initial research programs will provided.

A PERSPECTIVE ON OTEC PLANTS

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EXTENDED ABSTRACT

INTRODUCTION

Ocean Thermal Energy Conversion (OTEC) plants offer a number of advantages: reasonably favorable net-energy balance over the estimated 50-year life-span of a 160 MW(e) plant [1]; and it is essentially non-polluting in its operation except for the possible invasion. To the extent, however, that such plants can be located in areas in oceans that would not intrude and affect adversely the ecology in their proximity, and the density of such plants would be kept small, even this consideration would not, by itself, render such plants undesirable. Yet, with all these advantages, and the promise that such plants could well supply a substantial fraction of our energy needs, there are still reasons for not giving such research and development the highest priority.

ADDITIONAL CONSIDERATIONS

The several reasons for a very careful assessment of OTEC plants versus other, equally attractive alternatives [2] such as special purpose energy converters of sun, wind, and ocean waves for particular end uses: shopping centers, office buildings, apartment houses, individual residences, specific industrial uses; the use of biomass and hydrogen for vehicle propulsion, space heating; etc. The main reason is the very substantial material input, cement, heat exchanger metals, and others, material that could possibly be used more efficiently and to greater advantage for other purposes [3]. The second reason is either the nearly monastic lifestyle requirement for the crew, or excessive energy expense for transportation both because of frequency and location. Finally, there are such miscellaneous problems as the reliability of mooring, required level of training and maintenance care.

CONCLUSION

Consequently, decisions on OTEC cannot, should not be made on the basis of economic and net-energy analyses for these present only part of the picture. Scarcity of materials, stringency of demands upon the crew, need to be viewed not in terms of dollars alone but also in terms of alternative uses, because--if needed--legislation, regulations, tariffs, taxes can readily eradicate the apparent cost inequalities [4]. In terms of such an extended analysis, the development of full scale OTEC plants appears not nearly as attractive as on the basis of net-energy analysis alone.

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SOURCES AND POTENTIAL USES OF WAVE ENERGY

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EXTENDED ABSTRACT

Man must develop and use all possible energy sources if he expects to continue his technical advancement. Two energy sources that have been largely ignored are the oceans and large lakes. The oceans cover 70.8 percent of the earth's surface. Thus, they receive 70.8 percent of the energy from both the sun and the motion of the earth's atmosphere. Energy that is absorbed by the oceans in one location, either directly from the sun or from the winds, is transferred thousands of miles and held for days and even years before it is released.

Most calculations of ocean wave energy have used the concept that a wave is a single line of motion. The concept that the oscillating ocean is a three dimensional fluid greatly increases projections of energy availability. A system that is based on the surface area of the ocean utilized for energy transfer and conversion rather than the length of a system along a wave front has been constructed and tested. Theses criteria lead to an energy density within the ocean of approximately 10 kw/m^2 per meter of swell or wave height.

Uses of ocean wave energy can result in an effective savings of hydrocarbon fuel utilization. Conservation of energy derived from hydrocarbon fuels can be obtained by completely eliminating specific energy requirements of systems such as

- Public transportation systems
- Industrial complexes
- Municipal waste disposal systems
- Complete small cities

from the present electrical grid. Of course, in the case of emergency, these systems could be re-connected to the grid. Analysis of the potential energy savings of these uses of ocean wave energy is surprising.

Ocean wave energy also can be used to enhance energy storage techniques. Ocean wave energy is variable with time and energy storage system greatly increase the potential use the technology. Storage sysems such as:

- Hydrogen production
- Above ground pumped hydroelectric storage
- Underground pumped hydroelectric storage
- Compressed air storage, and
- Battery storage

can be used to handle the fluctuating nature of ocean waves.

Utilization of ocean or lake wave energy would greatly reduce pollution problems that would result from a hydrocarbon facility of the same capacity. An Ocean Swell and Wave Energy Conversion (OSWEC) system could be designed to serve both as a power source and a recreational facility. The structure would act as a haven for fish similar to off-shore oil derricks. Then, both a reduction in pollution and an ecological advantage would accure through the use of an OSWEC system.

A laboratory test system has been built and tested. The test system has been operated under two different configurations. Data from the tests indicate that a 50 to 100 megawatt OSWEC system could be constructed within two to three kilometers of the shoreline. Combining solar and wind energy with the ocean wave energy would result in an increase in the potential power production of the system.

An OSWEC system can be designed and built a relatively short distance off the coast with a connecting bridge, or a system could also be built completely at sea with no connections to the coast except for submerged power cables. A structure 100 meters in diameter would have the potential of producing from 2 to 6 megawatts of energy, considering a minimum wave of less than one meter, which would produce approximately 8.5 kw per oscillator and a maximum wave of 4.50 meters which would produce 25 kw per oscillator. During the day, two thirds of the energy would be produced by wave energy and one thrid by direct solar energy. Approximately two hundred forty (240) oscillators or wave amplification OSWEC systems would be located on the lower level of the complex.

SMALL SCALE POWER GENERATION UTILIZING WAVE ENERGY

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EXTENDED ABSTRACT

The conversion of the vast amounts of energy, in various forms, in the ocean into a useful form has preoccupied engineers and scientists for many decades. Stahl (1) presented a 70 page treatise in 1892 to the American Society of Mechanical Engineers, in California, in which he submitted several proposals for extracting energy from the ocean waves in view of the relatively high price of coal in that state. There is no evidence of any of Stahl's proposals being implemented at that time. For the next eight decades numerous other proposals were submitted worldwide.

However, even though the price of fossil fuels has increased markedly, estimates (2) for wave power generating units indicate that electricity generated from such units off the Southern African coastline would be 2 - 7 times more expensive than fossil fuel power generation. More recently, estimates from the United Kingdom (3) show at least a ten fold magnification of wave power generating costs to conventional generating costs. Another estimate (4) from the United States of America indicates that the installation costs of wave power units are 3 - 10 times more than those of conventional generating units.

Many of the devices being investigated by various institutions around the world are sophisticated extensions of Stahl's proposals. One of these is presently under investigation in the Department of Mechanical Engineering at the University of Cape Town, Republic of South Africa.

Silvers (5) and Martin (6) have reported on similar concepts but in both cases no further work has been reported. More recently, Masuda (7) and Meir (8) have shown that their air buoys are practical and feasible. The main difference between the latter two and that to be discussed in the paper is the method of transferring the wave energy. Whereas Masuda and Meir use the air-water interface as a 'mechanical piston', the author's system uses a float for the transfer of energy. The device in question has been termed the Differential Area Piston Compressor and is to be used to generate small quantities, (i.e. kilowatts) of power in constrast to other devices which are being designed to generate large (i.e. megawatts) of power.

Analysis of wave data recorded at several locations off the South African coastline indicates that power densities of up to 50 kW/m^{-1} of wavefront are available and this averaged over the entire coastline could supply all the power (electrical) requirements of the country up to the turn of the century. This, assuming 100% recovery and also that the entire coastline is used. (2)

It would seem, therefore, that the high cost of wave energy would completely rule out this alternative energy resource. However, like many other alternative energy resources, for example solar energy and wind energy, wave energy can play an important role in particular applications where only small amounts of power are required. Examples of these applications are floating buoys containing telemetry instrumentation or floating signal beacons. Small scale wave power generators could also be selectively applied to generate power for remote communities near the coast and isolated islands, (as is also envisaged for wind energy systems) where there are no indigenous fossil fuels and transportation of such fuels would be highly priced and in some cases beyond easy transportable reach.

The design criterion of a wave power device should be simplicity and hence the number of moving parts kept to a minimum, i.e. the system should require very little maintenance. The device in question has two moving parts - one being the vertical moving float-piston arrangement, and the other the Turbo-alternator. The working concept is that a large float, connected to a piston which has a smaller area than the float, moves in a vertical direction under impulse from the vertical movement of the wave. In doing so, the piston compresses air which passes through a turbo-alternator, via a storage accumulator. Each unit would have to be designed according to the wave characteristics of the considered area of application. For example, the South African coastal waters' mean tidal range is approximately 1,5 meters, and this will have an effect on the power output of a coastal unit.

The dimensions, power output and efficiency of a unit and the relationship between these and the wave characteristics are discussed. A test model of float diameter 0,6 meters is being tested in the University's wave flume, and a larger buoy of float diameter 3 meters and height 5 meters is being designed for sea trials.

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SESSION 5D

WIND ENERGY I

NEW DEVELOPMENTS IN WIND SYSTEMS TECHNOLOGY

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EXTENDED ABSTRACT

INTRODUCTION

Over the past two years, Rockwell International has provided support to the Department of Energy wind program by subcontracting the development of new small (under 100 kW) wind systems in a range of sizes. The objective of these subcontracts is to design, build and test prototypes for SWECS capable of producing energy at a cost competitive with conventional energy sources. While new wind systems are also being developed with private funds, the government-funded efforts reported here were undertaken to provide additional stimulation to the wind industry and help accelerate that time when wind energy will be able to provide a significant portion of the United States' energy requirements.

Multiple awards have been made to both large and small businesses to design wind systems in each of five general sizes. Design details are presented on the 1-2 kW, 8 kW, and 40 kW systems, prototypes of which are either nearing completion or currently under test at the Rocky Flats Test Center. Some general applications and requirements for these systems are:

- 1 - 2 kW - High-Reliability for remote applications in severe weather environments. Output is dc for charging batteries.
- 8 kW - For farm residences or other applications requiring a machine size around 8 kW. Output is 60 Hz ac for tie-in with a utility.
- 40 kW - For irrigation or small community applications. Wind systems are being designed for each of two power output formats - 60 Hz ac electrical (for utility tie-in) and mechanical.

In all three cases, the power designation is the minimum system output in a 9 m/s (20 mph) wind. A summary of the design criteria for these systems is given in Table I.

A variety of design configurations were selected for development into prototypes for testing. Advanced or innovative concepts that have not been proven were not included since emphasis was placed on developing designs suitable for near-term commercialization, both in terms of technical feasibility and, most importantly, for potential cost-effectiveness.

More recently, contracts have been awarded to develop a 4 kW system for single family residential applications and a 15 kW system for use on small farms, for

TABLE 1
WTG DESIGN CRITERIA

Program	Output Energy Requirements	System Life	Output Power Form	System Includes	Economic Goals (1978 dollars)
High-Reliability	1-2 kW @ 9 m/s (20 mph)	25 Years	24 VDC for Charging Batteries	All Components Except Tower and Storage Batteries	System Cost $1650/kW* For 1000th Unit FOB
8 kW	8 kW @ 9 m/s (20 mph)	25 Years	120/240 VAC 60 Hz Utility for Intertie	All Components Including Tower, Excepting Utility Interface Equipment and Foundation	System Cost $800/kW* For 100th Unit FOB
40 kW	40 kW @ 9 m/s (20 mph)	25 Years	440 VAC 60 Hz For Utility Intertie as well as Standalone. Also, Mechanical Output Shaft	All Components Including Tower, Excepting Foundations	System Cost $550/kW* For 1000th Unit FOB
4kW	Annual Energy Output of 7,500-15,000 kWh/yr with design envelope 3-6 kW @ 6.7-9.0 m/s (15-20 mph)	25 Years	120/240, 60 Hz For Utility Intertie	All Components, Except Foundations, Required for Complete Installation	Energy Cost 6¢/kWh in 4.6 m/s (10 mph) average wind regime
15kW	Annual Energy Output of 45,000-55,000 kWh/yr with design envelope 13-18 kW @ 7.1-9.0 m/s (16-20 mph)	25 Years	240/480 V, 60 Hz For Utility Intertie	All Components, Except Foundations, Required for Complete Installation	Erergy Cost 3¢/kWh in 5.4 m/s (12 mph) Average Wind Regime

*Based on Actual kW Output in 20 mph Wind.

light irrigation and small commercial operations. As with the other development programs, more than one design is being pursued in each case. This approach has been taken so that a variety of design concepts, details and fabrication approaches can be evaluated. At the same time, these contracts will serve to support and stimulate the newly emerging wind industry.

DESIGN SUMMARIES

1-2 kW

Markedly different design approaches have been taken by the three contractors designing this size system. One configuration is a three-bladed vertical axis machine, with the blades cyclically pitched during each revolution of the rotor. A second design uses a horizontal axis three blade fixed-pitch up-wind rotor which tilts back until the plane of rotation is parallel with the ground to achieve shut down in high wind. This is a design concept pioneered by Parris-Dunn in the late 1930s. The third design consists of a horizontal axis two-bladed down-wind rotor. Torsion bars are used in the variable-pitch hub mechanism which places the blades in stall at high wind speeds to protect the system. For all three designs, a reliability analysis was conducted to estimate how well the 10-year mean-time-between-failure requirement would be met.

8 kW

Three horizontal-axis systems are being designed in this size. All have down-wind variable-pitch rotors. One configuration uses a rigid three-bladed rotor, which incorporates coning to balance blade stresses in high winds. A second approach employs a "soft" three-blade rotor with each blade free to flap over a limited range to absorb loads from wind gusts. The third design uses a two-blade rotor with a pitch mechanism consisting of an elastic beam, free to flex in torsion, to which the blades are co-axially attached. This blade pitch mechanism concept is new, having been previously tested on wind tunnel models.

40 kW

Two designs are being developed for the 40 kW size machines. One has a three-bladed vertical axis configuration. The blades of this machine cyclically pitch during each revolution but follow an entirely different pitch schedule than the 1-2 kW design described above. The vertical axis power shaft will lend itself fairly easily to change-over from electrical to mechanical output. The other 40 kW system is a horizontal-axis down-wind machine incorporating two wound fiberglass tapered and twisted blades. Change-over to mechanical output for this design will also be possible though requiring more extensive work than the vertical-axis one.

*Cost goals based on the actual output in a 9 m/s (20 mph) wind--1-2, 8 and 40 kW are minimum power requirements at this wind speed.

CONCLUSIONS

Many design features have evolved from the present development contracts which show promise for contributing to cost-effective SWECS in volume production. While the original cost goals of $1500/kW for the 1-2 kW, $750/kW for the 8 kW and $500/kW for the 40 kW sized system* may not be met, projected system costs represent a significant reduction over those of most systems offered for sale today. This is particularly important since the environmental requirements for these designs are more severe than those to which the wind industry has designed to date. Taking projected unit cost for the 1000th to 10,000th system it is estimated that these SWECS can produce energy in the range of 3¢-10¢/kWh. These estimates assume volume production techniques and will vary with the type of user (homeowner, farm, etc.) and average wind speed where the system is sited. It must be emphasized that these projected energy costs assume a state of widespread commercialization for SWECS which, unfortunately, does not exist today. To realize these projected energy costs will require proving the designs through testing (currently just getting underway); resolution of numerous institutional issues such as utility rates and inter-tie procedures, and insurance availability and cost (for which studies are underway in another part of Rockwell's wind program at Rocky Flats); and establishment by the wind industry of a high volume production capability. Nevertheless, at this time the technology appears to be taking significant steps towards making wind energy a viable, cost-effective alternative.

RELIABILITY EFFECTS OF WIND INTEGRATION WITH A CONVENTIONAL ELECTRICAL UTILITY SYSTEM

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EXTENDED ABSTRACT

The potential impacts of incorporating wind turbines, as an example of an intermittent supply option, into a conventional electrical generating system were examined. The study focuses on the amount of electricity generation replaced by wind, the contribution of the wind turbines to the generating system reliability, and the methods used to calculate these benefits. A simple cost model was developed to estimate breakeven costs for wind turbines based on energy and capacity displacement savings. The capacity displacement savings are derived from "firm-capacity-equivalents": the amounts of dependable capacity that could replace the wind capacity and yield the same generating system reliability. The firm-capacity-equivalent of a conventional generating unit is less than its full power rating because of unavailability related to scheduled maintenance and forced outages. It is also affected by the size of the generating unit relative to the size of the utility generating system. Wind turbines have outages because of low wind speeds as well as maintenance and forced outages.

Variability of wind machine output over many years of wind data, wind turbine design, penetration of wind capacity into the system (up to a few percent of peak load), dispersed siting, and forced outage rates for wind machines were analyzed. Wind data from two Kansas sites with favorable wind conditions (Dodge City and Goodland) and a synthetic electric utility's hourly load data were used. The study examined wind turbine performance without the use of energy storage devices. The individual wind machines considered have rated capacities ranging from 100 to 2,500 kWe.[1,2]

The calculations were performed by inserting the wind turbines into the utility generating system. The available wind energy, after accounting for forced outage and scheduled maintenance of the wind turbines, was subtracted from hourly utility load data. A computer program, with generating system reliability and production-cost capabilities, was used to analyze the remaining load and the non-wind generating system. Com-

parison of cases with and without wind turbines yields the fuel displaced by wind (fuel type and cost) and the generating system reliability improvement attributable to the addition of the wind turbines. The firm-capacity-equivalent was determined from the improvement in the generating system reliability. Comparison of cases with and without wind turbines must be normalized to the same reliability criterion, such as a loss-of-load probability. The capacity savings, as well as the fuel savings, can be a key factor in determining wind competitiveness. [3,4]

One set of cases showed that the marginal value of additional wind turbines at a single site tends to decline as wind capacity added to the system increases. The marginal fuel savings (dollars) declines with added wind-generator penetration because energy from each successive wind-unit replaces energy: 1) from successively more efficient conventional units and 2) from units using less expensive fuel. The first effect was not significant in the cases studied, as indicated in the upper chart of Fig. 1.

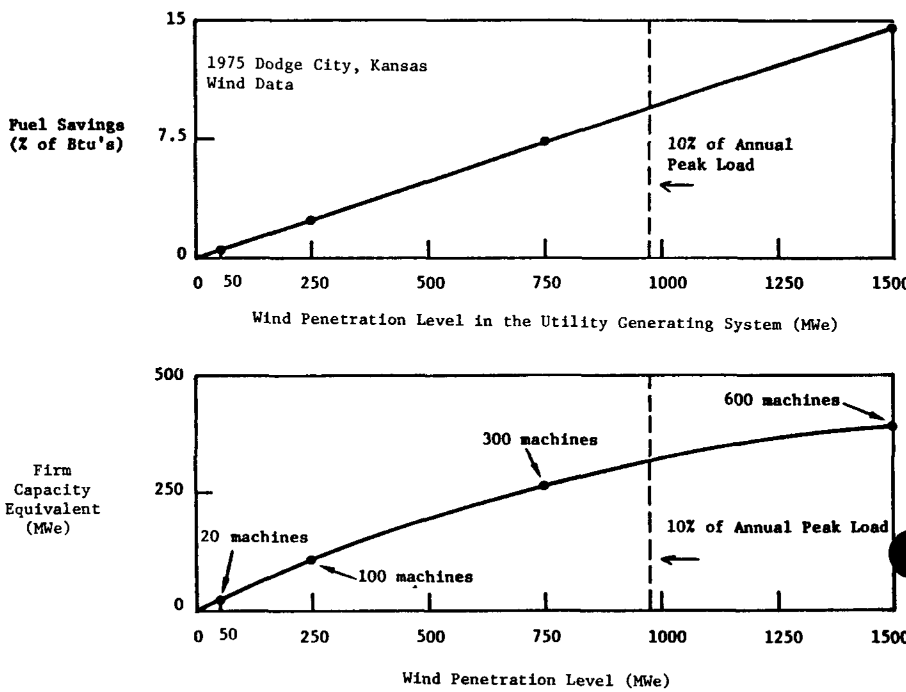

Fig. 1. Fuel Savings and Firm-Capacity-Equivalent as a Function of Wind Penetration at a Single Site for the DOE MOD-2 Design (2,500 kWe)

The saturation of capacity savings, as measured by firm-capacity-equivalent, is more rapid because not all hourly loads can be satisfied by wind. Saturation of capacity savings is evident, even at relatively low wind penetration, in the bottom chart of Fig. 1. However, even the 600th wind machine results in some increase in firm-capacity-equivalent.

The following represent other major findings of this study and are dependent on the generating system examined, load characteristics, location of wind data recordings, and other assumptions:

- Significant variations occur from year to year in wind energy availability.
- Characteristics of alternative wind-driven generators result in a wide range of energy responses and impacts on generating system reliability.
- Wind power may provide significant contributions to generating system reliability for small penetrations at a single site with no energy storage.
- Firm-capacity-equivalent, expressed as a percentage of installed wind capacity, can be greater than the corresponding wind machine annual capacity factor as a result of correlations between diurnal and seasonal patterns of system loads and wind speeds.

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THE FLOW FIELD ABOUT A VERTICAL AXIS WIND TURBINE

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ABSTRACT

The flow field about a straight bladed vertical axis wind turbine was investigated using a computed vortex model. The vortex model provided improved estimates of the 'inflow factors' which determines the degree of slowing down of the local flow through the turbine and is important in turbine performance calculations. The study also produced a model of the local flow field used to determine coherent flow structures which are developed by the turbine blades. These coherent flow structures could persist downstream and not only buffet the other rotor blades but also contribute significantly to the wake structure of the turbine and affect any other turbine positioned further downstream. An important aspect, concerning the design of vertical axis turbines, is to estimate the extent of the blade vibrations induced by forces due to the local turbulent flow.

In the paper the recent approaches to determine the performance of vertical axis turbines are introduced. Similarly, as several other authors, a streamtube theory for prediction of the turbine performance was derived and computer programs written. It was shown that the variation of the inflow factor bore a close approximation to the angular position of the blade $|\sin \theta|$ relative to the free stream flow direction, especially in the operating range of tip speed ratio (T_{SR}) 4 to 6. The amplitude of the blockage factor function was shown to increase with increasing tip speed ratio and wind turbine solidity. A particular deficiency in present theories is the estimation of the degree of modification of the flow field due to the rotating turbine. The effect of the inflow factors is to change the angle between the total velocity vector and the direction of rotation and thereby the true angle of incidence of the turbine blade which determines the forces and torque on the turbine blade.

In a real fluid, the vorticity fields which exist downstream of a rotating aerofoil are distributed throughout the region. In the present analysis the vorticity distribution was represented by vortex filaments. In the analysis a trailing vortex system was used by applying the Biôt-Savaart law similarly as in three dimensional aerofoil theory. As the straight blade rotated about a fixed point, a 'horseshoe vortex' system made up of elemental line vortices was shed from the aerofoil. The vortex system was closed by a starting vortex and completed by a bound vortex in the aerofoil with circulation strength which depended on the local aerofoil lift force, calculated from blade element and streamtube theory. Hence, at the end of every time increment a rectangular vortex pattern was shed from the aerofoil and was convected downstream to be influenced by the free stream flow and the previously shed vortices. In the study besides a trace showing the path of the rotating turbine blade wake, the velocity field that existed at another diametrically opposite turbine blade was calculated and presented as a velocity time history. The velocity change with time at a fixed point, one diameter downstream of the turbine was also calculated.

Eventually the computed vortex models will enable estimates of large model wind turbine performance to be made and also improve the determination of critical blade vibrations which is so important for the safety of wind turbines used as an alternate energy source.

DYNAMIC RESPONSE OF POWER GENERATING WIND TURBINES*

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EXTENDED ABSTRACT

A model is presented of the rotational dynamics of a large wind turbine driving synchronous and non-synchronous electric generators. The rotor is assumed rigid with constant-chord blades and is modeled by aerodynamic strip theory. The loads include a DC generator with either field current control or blade pitch control and a synchronous alternator with blade pitch control. These models are used to evaluate rotational response of the wind turbine to step-changes in wind speed.

Rotor design requires a compromise between efficiency and cost, both of which increase with rotor solidity. A high solidity rotor, i.e. one with many wide blades, is efficient because it can extract the maximum energy from the wind while rotating slowly. Drag losses are small, leaving more energy for useful work. A low solidity rotor costs less because it has fewer, narrower blades. The 150 foot diameter rotor used here had a solidity of 0.16 and a design speed ratio (wind speed divided by rotor tip speed) of 0.125. Its maximum efficiency was 0.78 based on the maximum energy which can be extracted by a single actuator disk. The wide range of rotor operating conditions required that blade stall and aerodynamic transients be accounted for.

Direct current and synchronous alternating current machines each have advantages and disadvantages. Because their speed need not be constant, DC generators may allow the rotor to run at its most efficient speed for a given wind speed. This is done by keeping the speed ratio the same for all operating conditions. Thus as wind speed increases, rotor speed must increase proportionally.

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* Based on a Master of Mechanical and Aerospace Engineering thesis by D. W. Adkins with M. I. Young as advisor.

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Synchronous alternators run at constant speed and allow less efficient rotor operation. However, since most electrical power is transmitted and consumed in the form of alternating current, their output is directly useable. The alternator model used here assumes torque is proportional to the sine of the power angle, which is the lead angle between the induced voltage and the load voltage. When the power angle is zero the induced voltage and load voltage exactly oppose each other and no current flows. Although the rotor turns at synchronous speed, no power is generated. The rotor must drive the alternator slightly ahead of the load to generate power. Damping can be built into synchronous alternators and is included in the analysis. It acts only when the alternator is running at non-synchronous speed and reduces speed oscillations after a disturbance.

Control systems may be used with these machines to maintain optimal operating conditions or prevent overloading the generator in high winds. The direct current machine was evaluated with field current control to maintain constant speed ratio. Since an error type control signal proportional to speed ratio is difficult to generate, the system considered employs a linear approximation based on rotor speed. Both machines were evaluated with blade pitch control to prevent current overload in high winds. For a synchronous machine, current overload can also be prevented by sizing the alternator for the peak rotor output. Since the constant speed rotor stalls in high winds, its power output diminishes, thereby protecting the alternator.

The differential equations modeling these systems were solved numerically using a fourth-order Runge-Kutta method with variable step size. The rotor torque was calculated at each step using a Simpson's Rule algorithm.

The analysis shows that a fixed pitch rotor driving a DC generator or non-synchronous alternator over a narrow speed range responds as a first order system. However, for a large change in wind speed the response is found to be very different. After a large change in wind speed the inboard part of the rotor is stalled so rotor acceleration is slow. As the rotor speeds up less of it is stalled, and it accelerates faster. As the rotor approaches its new equilibrium speed it behaves as a first order dynamic system.

With blade pitch control both the DC and synchronous machines experience large output current surges from a step-change in wind speed. In this case the analysis shows the response is similar to a second order dynamic system. The generator and alternator may have to be oversize to withstand the current loads if wind gusts are expected.

AN UNCONVENTIONAL WIND MACHINE

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ABSTRACT

It is the purpose of this paper to introduce an unconventional wind machine which has economics comparable with nuclear power and is already available in the public market place. Some of what used to be simple facts of power production economics seems to get totally lost when one operates in the current age of alternative energy sources, conservation claims, and emotionally grounded fears of some energy choices. It is the purpose of this paper to show that a slight perturbation in the economic analysis and logic of the old days indicates that an idea generally ruled out as a costly addition is in reality a very competitive WIND MACHINE. By very competitive, one means substantially more economic than the wind machines now under consideration and, indeed, sometimes more competitive than nuclear power itself.

Specifically, about 17 MWE could be saved for other uses such as sale in most 1000 MWE plants of any type -- nuclear, oil, gas, peat, or wood -- which use conventional electrically driven fans in their cooling towers. The savings of 17 MWE or viewed equivalently, the generation of 17 MWE for grid use is obtained by the installation of natural draft cooling towers. A natural draft tower being obviously a WIND MACHINE.

The capital cost for such a switch will be shown here to be competitive with proposed wind machines as well as often competitive with oil and nuclear power. Therein rests the case for this simple unconventional WIND MACHINE.

The economic comparison depends upon site conditions to a fairly extensive degree so that here it is desirable to mostly look at averages. More detailed results are left to the full paper. However, the range of variability leads one correctly to expect similar conclusions for most all cases. A simple rule of thumb cited by the Marley Corporation [1] in about 1973 for construction in 1976 is that hyperbolic natural draft towers cost about 3 times that of conventional wood fan draft towers. In estimated 1976 dollars that was $23.00 per tower unit as defined by Marley. The natural draft tower is only about twice as costly as concrete fan draft towers if this tower is desired or necessary. The total capital costs for fan draft towers in Marley's examples of near the 1000 MWE size

adjusted for size effects was 2.65 million dollars [1] with a range of ±17%. These numbers are expected actual capital costs in 1976 dollars. Natural draft towers in these examples did hold to their factor of about three and hence come in at about 8 million dollars. The capital costs for backfitting towers, the cost of the unconventional wind machine, is seen to be $485.00 per KW. If a new plant is being designed, the net cost is $323.00 per KW. It is well accepted that operating costs for a natural draft tower are less than for fan draft since no rotating machinery is involved. However, the operating costs are usually born by the main plant itself. If this logic holds, the WIND MACHINE operating costs are then negative. Perhaps more fair would be to determine the actual costs and proportion them on some equitable basis. More logical would be to assign them on the basis of a fair share of the total plant operating costs which is alright for our purposes here. That is, even for the latter case, power from the unconventional wind machine is produced at a lower cost than power from the main unit.

The total power costs can most simply be compared by looking at nuclear power plant costs in general and making reference then to other wind machines from this point of reference. The operating costs we have seen favor the wind machine, and nuclear power plant actual capital costs in 1975 were being projected at $500 to $750 per KW depending on specific plants all of which were to be completed in 1976 to 1978 [2]. Clearly, the estimated capital costs for the unconventional WIND MACHINE are below this and hence the cost of power produced is less than that for a main plant which is nuclear.

The comparison with more conventional wind machines can then most easily be made by comparing their cost of power production to that of nuclear power plants. A recent DOE report will be used to accomplish this end [3]. The cost of power production from conventional wind machines varies as the cube of the wind speed (as an aside, note that this is not true for the unconventional wind machine which is controlled by ambient air temperature). Thus the cost of power is very strongly tied to the suitable average wind speed which the machine was designed for and that which actually exists at the site. In any event, power cost estimates in 1977 dollars for a 1.5 MWE unit are 60 to 80 mills per KWH for wind speeds of 8 and 6.4 m/sec. Nuclear costs are sited in the same paper to be 4 mills per KWH. These conventional wind mill numbers are extrapolations of costs for the second unit cost out to that of the 100 unit using a learning curve with a 0.95 parameter. We have seen the unconventional WIND MACHINE costs as more favorable than nuclear power costs. Now we see that nuclear power costs are more faborable than conventional wind machine costs by a factor of 7.5 to 10. Unconventional WIND MACHINES are seen to be clearly a device we should not consider lightly.

In summary, the unconventional WIND MACHINE has been shown to have very faborable economics. One must conclude that any serious commercial expenditure of funds - as opposed to research test expenditures - should be directed towards the unconventional WIND MACHINE at least until this resource is exhausted (all existing plants have been backfitted).

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ELEVENTH STREET AND BRONX FRONTIER: URBAN PIONEERING WITH WIND POWER

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EXTENDED ABSTRACT

Wind energy is being applied to electricity generation at two locations in New York City. These small-scale systems are pioneering efforts contrasting with large wind turbines (such as the 2 MW experimental DOE-NASA unit recently set up in the Blue Ridge Mountains near Boone, N.C.), in that they are located in an urban setting, seek to exploit relatively low-velocity winds, and represent initiatives by neighborhood associations and community groups rather than by government or utilities. However, they draw financial assistance from government, and interface with the electric utility serving the area (Consolidated Edison Company of New York). For these and other reasons the projects raise questions of energy technology, finance and policy, and thus assume importance exceeding their tiny size in capacity and energy supply.

519 EAST 11TH STREET

In spring 1976 neighborhood and community organizations, working to rehabilitate deteriorated and abandoned tenement houses in the lower east side of Manhattan Island, launched plans to install a 2 KW wind turbine (three blades, 13' diameter swept area) on the roof (60' above street level) of the 5-story structure at 519 East 11th Street. Wind conditions were estimated to be adequate for electricity generation at costs comparing with (even cheaper than) those charged by the area utility. A rebuilt Jacobs wind machine was mounted on a 37' Rohn tower. (Figure 1.) Cut-in wind velocity was calculated to be 7 mph; rated-speed velocity 22 mph; and shut-off (furling) speed 40 mph. A synchronous inverter was incorporated in the system, to convert the turbine-generator's d.c. to a.c. at standard line voltage and frequency. Planning and initiative were largely by a community-based group called the Energy Task Force, which has described the project and its specifications. [1] The wind turbine was operational from late 1977 till early 1979 (when needed repairs and replacements forced a shut-down), providing electricity for lights in the building's halls (totaling about 250 watts) and for two 250-watt pumps circulating working fluid through roof-mounted solar collectors providing hot water for tenants. Data recorded during the period of operation so far do not yet permit assessment of performance.

BRONX FRONTIER

Neighborhood groups in the South Bronx, working through the Bronx Frontier Development Corporation, have set in motion several impressive projects to rehabilitate and upgrade that badly blighted part of the city. (As in the 11th Street area, blacks and people of Hispanic-American origin loom large in the population; sociological and other factors underlie a history of

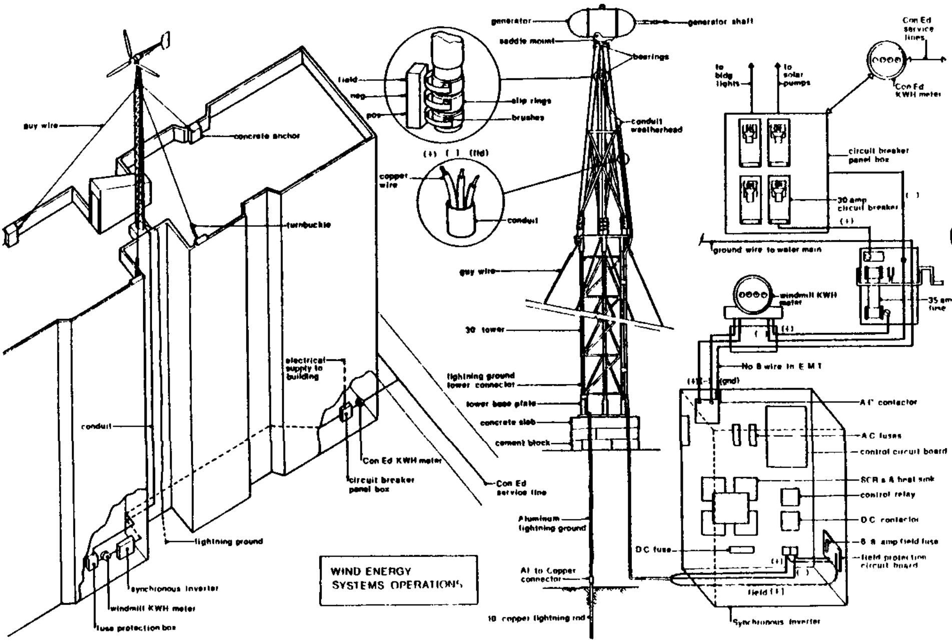

Figure 1: 519 East 11th Street, Wind Energy Systems -- Drawing by Energy Task Force (op. cit.). Note: In present author's full-length paper this figure is enlarged, hence clearer. Reproduction here does not necessarily imply that all specifications shown are fully compatible with engineering requirements or preferences of the electric utility responsible for area power supply. Some relevant points are addressed in the paper.

decay, housing abandonment, arson, other crime and juvenile delinquency, now, it is hoped, being reversed.) One effort is the "greening" of formerly rubble-strewn vacant lots with neighborhood vegetable gardens. These are fertilized with humus derived from windrows of compost aerated, at Bronx Frontier's Hunts Point site, by a 10-ton "Scarab compost turner." The plan is to improve the composting process with perforated plastic pipes through which ventilating air will be forced; power for this is to be furnished by a 40 KW wind turbine (four blades, 40-foot diameter swept area) mounted on a 64' tubular steel tower. Electricity is to flow to a bank of industrial storage batteries, thence, via synchronous inverter, to electric air-blowers. Excess power, when and if available, will be fed into the utility's grid, as was and remains the plan at 11th Street. The schedule called for mounting the turbine on the tower Sept. 13, 1979, and for start-up about a month later. Wind regimes at Hunts Point (across the East river from LaGuardia Airport) are considered favorable.

PROSPECTS

Objective appraisal of these two (and similar) efforts involves technical, economic, and policy questions, some of which are explored in this paper. As just one example: the utility is necessarily concerned with safety, and with guarding its system against intolerable distortion to its sinusoidal voltage and current waves. For another, the economics depend critically on site-specific and time-specific wind patterns, which are variable and erratic in a big-city environment. A forthcoming academic study examines such issues. [2] Another example of thorough analysis is an Electric Power Research Institute study in cooperation with utilities in northern New York State and Kansas, and the west group of the Northwest Power Pool. [3] Consolidated Edison is itself researching New York City-area wind resources and potentials, with wind monitoring and other scientific work by an electrical engineering college department in Manhattan. The findings of these and other rigorous studies can conceivably benefit wind-energy undertakings such as 11th Street and Bronx Frontier, whether or not their sponsors wish an interface with the utility. (At least one wind-turbine experiment, incorporating a low-speed vertical-axis design, is under way in Manhattan, involving no electricity generation -- simply heating of water for the building -- and hence no need for coordination with a utility.)

Broadening the perspective, community wind- and solar-electric initiatives, commendable as they may be in certain ways, can entail a danger of diverting attention and resources from the starkly immediate need to bolster New York's bulk power supply via existing large-scale technologies and fuel sources, and to break the near stifling grip fastened on the city by present heavy and needless dependence on expensive oil, especially imported. [4] The prospects for future success of community-based wind-energy efforts -- and the ultimate hope for at least some measurable contribution by them to urban energy supply -- depend on evaluation of factors like these, and also on a spirit of accomodation and businesslike cooperation between community and utility.

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SESSION 5E

HYDROGEN ENERGY IV

An Exergetic/Energetic/Economic Analysis of Three Hydrogen Production Processes. Electrolysis, Hybrid, and Thermochemical

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ABSTRACT

This paper presents the results of a combined first and second law analysis, along with capital and operating costs, for hydrogen production from water by means of electrolytic, hybrid, and thermochemical processes. The processes are SPE and Lurgi electrolysis with light water reactor power generation and sulfur cycle hybrid, thermochemical and SPE electrolysis with a very high temperature reactor primary energy source. Energy and Exergy (2nd law) flow diagrams for the process are shown along with the location and magnitude of the process irreversibilities. The overall process thermal (1st law) efficiencies vary from 25 to 51% and the exergetic (2nd law) efficiencies, referred to the fuel for the primary energy source, vary from 22 to 45%. Capital and operating costs, escalated to 1979 dollars, are shown for each process for both the primary energy source and the hydrogen production plant. All costs were taken from information available in the open literature and are for a plant capacity of 100×10^6 SCF/day. Production costs vary from 10 to 18 \$/GJ, based on the higher heating value of hydrogen, and are based on a 90% plant operating factor with a 21% annual charge on total capital costs.

NON-CORROSIVE, TWO-REACTION, LOW TEMPERATURE T/C CYCLES

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EXTENDED ABSTRACT

Introduction

In the beginning, Funk and Reinstrom [1] showed that two-reaction thermochemical cycles for producing H_2 and O_2 from H_2O incorporating metal oxides or metal hydrides are unlikely and probably impossible at reasonable temperatures. On the other hand, as Abraham and Schreiner [2], among others, have pointed out, provided reactions involving H_2O and O_2 and/or H_2 and entailing reaction entropy changes of the order of 100 eu are found, closed, two-reaction, cycles incorporating such reactions will engender favorable operating temperatures. To date lack of knowledge of such reactions has led to four and five reaction cycles in order to keep process operating temperatures within practical limits [3].

Minimizing the number of reactions required to decompose H_2O into its constituents has long been a practical objective. The number of reactor vessels, heat losses, and materials handling problems are lessened by reducing the number of separate chemical reactions involved. Current efforts worldwide incorporate costly electrochemical reactions in an attempt to avoid using multi-reaction steps to close the cycle.

The author was intrigued that hypothetical aqueous solution two-reaction cycles are possible using redox reactions based upon the aqueous solution Eu^{2+}/Eu^{3+} reaction couple. Calculations using recent data on the lanthanides [4], indicated that separate O_2 producing and H_2 producing redox reactions would be possible for temperatures of 882°C and 182°C, respectively, providing the impossibl conditions can be met that gaseous H_2O and the aqueous solution exist simultaneously at elevated temperatures. What is requir apparently, is a solid state solvent possessing the electrolyti properties of water.

The appearance in 1977 of the pioneering paper of Kasai and Bishop [5] provided the incentive for the present work. In this paper qualitative results on measurements of O_2 and H_2 production from H_2O using mordenite-hosted redox reactions employing Cr^{3+}/Cr^{2+} and In^{3+}/In^{2+} couples were reported. The results support the conclusio that mordenite can serve as a solid state ionizing solvent at elevated temperatures.

A study of the known properties of the various groups of zeolites as described, for example, in Breck [6] reveals that mordenite is relatively unique in that the main passages within which redox reactions of interest take place can be described by a simple geometrical model. The present research began with the construction of a mathematical model to describe the reaction chemistry for mordenite-hosted redox reactions of concern to two-reaction T/C cycles for making H_2 and O_2 from H_2O.

Discussion

Central to this research is the thermochemical model for the two-reaction, mordenite-hosted, cycle described below:

$$(1-F)H_2O(g) + \frac{2}{m} MX_n \cdot pH_2O(s) \rightarrow \frac{2}{m} MX_{n-m} \cdot qH_2O(s) + 2HX \cdot rH_2O(s) + \frac{1}{2}O_2(g) \quad (1)$$

$$F\,H_2O(g) + \frac{2}{m} MX_{n-m} \cdot qH_2O(s) + 2HX \cdot rH_2O(s) \rightarrow \frac{2}{m} MX_n \cdot pH_2O(s) + H_2(g) \quad (2)$$

$$H_2O(g) \rightarrow H_2(g) + \frac{1}{2}O_2(g) \quad (3)$$

Reactions (1) and (2) contain all the variables exercised in the present research. These variables are:

M; the metal used
n, n-m; the intermediate oxidation states of M
p, q, r; inner sphere H_2O coordination or hydration numbers for M^{n+}, $M^{(n-m)+}$ and H^+, respectively
and Si/Al ratio.

F is determined by m, p, q and r and is required to make reaction (1) and (2) sum to be reaction (3). That is

$$F = \frac{2}{m}(p - q - mr)$$

The variation of ratio Si/Al varies the anionic strength of the mordenite lattice. The ratio enters into the thermochemistry through the definition of the unit anion, X^-, viz.

$$X^- = [(SiO_2)_\lambda AlO_2]^-$$

where λ = Si/Al. As λ increases the concentration of anionic sites in the mordenite lattice decreases, the mass of an anionic site increases, and the distance between anionic sites lining the mordenite channels increases.

The model for the reaction enthalpy and entropy for reaction (1) incorporates separate terms for lattice energy (Madelung energy), cation-H_2O solvation, and highest oxidation state cation reduction potential, E^o. This model was exercised for reaction total pressures of 68 atmospheres and several combinations of metals, M, oxidation states, n, (n-m), H_2O inner sphere solvation numbers, p, q, r and mordenite lattice Si/Al ratios, λ.

It is interesting to note that the results of these thermochemical calculations are consistent with the recent hypotheses of Barthomeuf [7] who suggests strong analogies should exist between the physicochemical properties of zeolites and the established properties of liquid electrolyte solutions. Indeed, as Barthomeuf anticipates, the reaction model developed in this research has been derived using the activities of all species participating in the reaction chemistry.

Results

The principal results are curves of cycle efficiency or figure of merit, η, plotted vs. cation highest oxidation state aqueous reduction potential, E^o, with Si/Al = λ and the temperatures T_1(K=1) and T_2(K=1) as parameters at fixed values of combinations of the parameters n, m, p, q and F.

Thirteen promising cycles are identified based upon cation oxidation states of the metals Cr, V, Fe, Cu, Ni, In, Tl, Ho, Pm, Sm, Yb, Eu, and U. Values of η ranging from .35 to .50 for reaction equilibrium temperatures, T_1, of 827°C or less were obtained including reasonable heats of separation of H_2O from the O_2 and H_2 reaction product streams.

Conclusions

1. Calculations for appropriate mordenite=hosted redox reactions identify at least 13 possible two-reaction T/C cycles all having superior cycle efficiencies at reaction equilibrium temperatures below 827°C. The product gases are generated at 68 atmospheres

2. H_2 (and O_2) production gacilities based upon such cycles possess the following advantages vis-a-vis competing T/C cycles
   A. Only two chemical reactions are involved
      (1) Fewer reactor vessels
      (2) Less exposure to heat losses
      (3) Less materials handling and potential loss
      (4) Fewer reactions to check in the laboratory
   B. No corrosive materials are involved
   C. No volatile compounds (such as metal-halides) are involved
   D. All gas-solid reactions with only H_2O as reactant. Product separations are facilitated
   E. Solids involved cannot fuse such as metal-halides do

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STATUS REPORT ON THE WESTINGHOUSE HYDROGEN PRODUCTION PROCESS

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EXTENDED ABSTRACT

The Westinghouse Hydrogen Production Process is a hybrid electrochemical/thermochemical process for decomposing water into hydrogen and oxygen. The production of oxygen occurs via the thermal reduction of sulfur trioxide obtained from sulfuric acid, i.e.,

$$H_2SO_4 \rightarrow H_2O \;+\; SO_3 \rightarrow H_2O \;+\; SO_2 \; 1/2 \; O_2 \quad (1)$$

The process is completed by using the sulfur dioxide from the thermal reduction step to depolarize the anode of a water electrolyzer. The overall reaction occurring electrochemically is:

$$2H_2O \;+\; SO_2 \rightarrow H_2 \;+\; H_2SO_4 \quad (2)$$

The net result of Reactions 1 and 2 is the decomposition of water into hydrogen and oxygen and the sulfur oxides are involved as recycling intermediates. Although electrical power is required in the electrolyzer, much smaller quantities than those necessary in conventional electrolysis are needed.

The cycle (frequently called the Sulfur Cycle) has the potential for achieving high thermal efficiencies while using common and inexpensive chemicals. The product hydrogen and oxygen streams are available under pressure and at high purity. As a result, these products may be pipelined and used without detrimental environmental effects. Conceptual designs and cost estimates for large hydrogen production facilities using this process have been prepared and have shown overall thermal efficiencies of close to 50 percent. The estimated costs of hydrogen production favorably compare to alternate long term systems employing water electrolysis or coal gasification.

The program for the development of the process has been underway since 1973, with Westinghouse funding, and has been supported by the United States Department of Energy since 1976. The development plan is a multi-year program leading to a pre-pilot integrated bench scale cyclic process demonstration unit (PDU) by 1983. Pilot scale and/or demonstration units are planned after experience is gained with the PDU.

There are four major areas presently underway in the program: electrolysis, sulfur trioxide reduction, process studies and integrated performance testing. This paper briefly highlights the status of the work in each task with emphasis on the results of process studies that have indicated the potential attractiveness of using solar energy to drive the process and to produce synthetic fuels or chemicals using hydrogen as a feedstock.

Scoping studies have been performed to identify specific chemical or synthetic fuel processes that could be integrated with a solar/hydrogen plant. Five processes were selected for concept evaluation: ammonia synthesis, methanol synthesis, hydrogen peroxide manufacture, direct iron ore reduction, and coal liquefaction. The studies were based on the use of heliostat fields and solar central receivers to absorb the concentrated solar flux. A "conventional" solar receiver is used to generate steam for electric power generation, while a high-temperature (1600°F) receiver is employed for the thermochemical step of the Sulfur Cycle (i.e., sulfuric acid vaporization and decomposition). Energy storage systems are used to permit continuous operation of the chemical process. Thermal energy storage (oil/rock sensible heat) is used for electric power generation at night. Chemical storage in the form of sulfur dioxide is used for the thermochemical step by decomposing surplus acid during periods of insolation to charge the storage tanks.

Single solar central receivers are limited in capacity by the physical constraints of heliostat distance from the receiver and by tower dimensions. "One-module" capacities for each process were estimated using a single high-temperature receiver and a single-steam receiver. Larger capacities could be obtained by using multiple modules. Although relatively small, the ammonia and methanol plant capacities may represent attractive plant sizes for market areas such as the southwestern United States. The hydrogen peroxide plant capacity is larger than necessary, and a scaled-down plant could be designed. The capacity for direct reduction of iron ore is comparable to medium-sized fossil-fuel direct reduction plants. Since the sponge iron product can be processed in an electric furnace, there are no overriding scaling factors similar to those that determine the capacities of conventional steel making facilities.

Each of the concepts was judged to be technically feasible and environmentally attractive. The ammonia and hydrogen peroxide plants require only solar energy, air and water to function. The methanol plant requires a carbon source, which could be carbon dioxide recovered from flue gas, calcining operations, air or sea water. The direct iron ore reduction plant is particularly attractive from an environmental standpoint. It uses solar energy and water to reduce iron ore to sponge iron, which can be made into steel in an electric arc furnace, thus eliminating the need for coke ovens, blast furnaces, and basic oxygen furnaces.

In summary, several potentially attractive solar fuel and chemical plant concepts have been identified using the Sulfur Cycle as an intermediate process for producing hydrogen. These concepts offer attractive alternatives for producing synthetic fuels or hydrogen-rich chemicals without the need for fossil fuels to produce hydrogen. Preliminary economic estimates indicate product costs somewhat greater than costs with plants that use fossil fuels. As anticipated, the dominant capital costs are associated with the solar energy and energy storage subsystems. However, this trend is consistent with numerous evaluations of solar electric power plants that use comparable technology, i.e., central receivers and heliostat collector fields. Since the solar collection and storage portions of the plants represent almost two-thirds of the total estimated capital investment, this is the area where the greatest reduction in costs can be obtained. DOE's programs for advanced heliostat design, high-temperature solar receivers, and advanced storage systems are aimed at reducing these costs. In addition, continuing development on the Sulfur Cycle should permit reduction of the hydrogen production costs. It would be premature at this point to make projections of breakeven fossil fuel prices or plant payback periods. The results to date in effect represent scoping studies aimed toward identifying potential candidate solar fuels and chemicals processes, and determining first-cut approximations of technical performance and economics.

STATUS OF THE DEVELOPMENT OF THE GENERAL ATOMIC THERMOCHEMICAL WATER-SPLITTING CYCLE

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[EX]TENDED ABSTRACT

INTRODUCTION

Progress in the development of the General Atomic (GA) sulfur-iodine thermochemical water-splitting cycle over the last 18 months is reported in this paper. The major accomplishments have been:

1) Significant improvements in the chemistry of the process.
2) Development, review, and revision of an engineering flowsheet.
3) Screening, identification, and testing of potential materials-of-construction for the corrosive process fluids.
4) Increase of the process efficiency to ∿47% with additional increases projected to reach ∿50%.
5) Small-scale demonstration of the cycle in a closed loop under recycle conditions.
6) Installation of the next phase of scale-up equipment (bench-scale) and demonstration of parts of the process in this equipment.

The results of the work carried out during the last year have demonstrated that thermochemical water splitting by the sulfur-iodine cycle is a feasible process and have provided confidence that acceptable thermal efficiencies in the range of 50% are achievable.

The GA sulfur-iodine cycle can be described by the following three chemical equations:

$$xI_2 + SO_2 + H_2O \rightarrow H_2SO_4 + 2HI_x \qquad 370\ K \qquad (1)$$

$$2HI_x \rightarrow H_2 + xI_2 \qquad 393\ K \qquad (2)$$

$$H_2SO_4 \rightarrow H_2O + SO_2 + 1/2\ O_2 \qquad 1123\ K \qquad (3)$$

In these equations, HI_x represents the average of several HI_n compounds formed in the initial solution reaction. Separation of the H_2SO_4 and HI_x takes place under gravity, since the two acids are nearly immiscible. The upper phase contains most of the H_2SO_4, and the lower phase contains most of the HI_x.

The main attributes of the cycle are that its thermal efficiency is expected to be high (about 50%) and that it can be conducted as an all-liquid and gas-phase process, a characteristic that should give it considerable engineering advantage over any cycle requiring solids handling.

The process development is proceeding in four major areas: 1) Basic chemical investigations; 2) Materials investigations; 3) Process engineering studies; and 4) Bench-scale testing.

STUDIES

Basic Chemical Investigations. The sulfur-iodine cycle process can be broken down into four major chemical operations: 1) Main reaction and product phase-separation; 2) H_2SO_4 concentration and pyrolysis; 3) HI separation; 4) HI decomposition.

Each of these unit operations has been demonstrated and significant improvements have been made. At present, a part of the chemistry effort is devoted to collecting detailed data for the process engineering design and bench-scale work, while efforts to improve existing technologies and develop alternate process methods with improved efficiency are continuing.

In the main reaction, the acids H_2SO_4 and HI_x are produced from H_2O, SO_2, and I_2 and are separated from each other. Continued work in this area has led to operating conditions which result in a conversion equivalent to 57 wt% H_2SO_4. This is a significant improvement in product yield over earlier results.

No additional work has been carried out in the area of sulfuric acid concentration and decomposition. Earlier work showed that acceptable decomposition rates of H_2SO_4 can be easily achieved below 1123 K using catalysts.

The lower phase of the main reaction contains HI, I_2, and H_2O. The HI needs to be separated from the H_2O and I_2 before the HI can be decomposed efficiently. Work last year has resulted in the design of a countercurrent extraction column where HI and H_2O are extracted with phosphoric acid. The separated I_2 is recycled into the main process. The HI is separated from H_2O and H_3PO_4 in a distillation column.

Work on the HI cracking has centered mainly on the development of catalysts for the decomposition of HI. A process has been developed where this decomposition is carried out in the liquid phase at HI decomposition temperatures as low as 393 K.

Process Engineering Studies. The sulfur-iodine cycle consists of five distinct sections: 1) Section I produces the acids H_2SO_4 and HI from H_2O, SO_2, and I_2. The SO_2 that is fed to this section contains all the O_2 generated by the decomposition of the H_2SO_4. The O_2 product is removed from this section. 2) Section II concentrates and decomposes H_2SO_4 received from Section I. 3) Section III removes the very small amount of dissolved H_2SO_4 and unreacted SO_2 from lower phase product [HI_x (sol)] and then separates it into HI, I_2, and H_2O using H_3PO_4. 4) Section IV decomposes HI into H_2 and I_2 and separates products. The H_2 product is taken from this section. 5) Section V, not shown in the figure, is the intermediate helium loop that combines the helium-related parts for the delivery of nuclear heat and the generation of process power.

A second iteration of the flowsheet has been completed. The second iteration incorporates several new process improvements into the flowsheet, resulting an increased theoretical efficiency to approximately 47%.

Bench-Scale Testing. In 1977, GA started the design and construction of a bench-scale unit aimed at carrying out the reactions of the sulfur-iodine cycle in a continuous mode. The main objective of the bench-scale unit is the study of the cycle under continuous flow conditions by modeling the main solution reaction, product separation, and concentration and decomposition of H_2SO_4 and HI. The unit is divided into three subunits: Subunit I (main solution reaction), Subunit 2 (H_2SO_4 concentration and decomposition), and Subunit 3 (HI concentration and decomposition). The unit has been designed for an H_2 production rate of $\sim 6.6 \times 10^{-5}$ m^3/s ($\sim$4 liters per min.).

Subunit 1. In this subunit, the main solution reaction is carried out. The H_2O, I_2, and SO_2 are injected in a contact reactor where the two acid phases are formed. The products are then passed into a gas separator, where the excess SO_2 is removed for recycle, and eventually into a liquid-liquid separator, where the two phases are separated and collected.

Subunit 2. The H_2SO_4 phase from Subunit 1 is purified, concentrated, and pyrolized at temperatures up to 1144 K. Uncracked H_2SO_4 is recycled to the concentration column, and wet SO_2-O_2 product may then either be passed to a caustic scrub prior to metering and discharging or recycled to Subunit 1 without removal of O_2.

Subunit 3. This subunit separates HI from the lower phase product of the main solution reaction (containing HI, I_2, and H_2O) by a treatment with concentrated H_3PO_4. The HI is then catalytically decomposed at moderate temperature.

Status. A new enclosure has been constructed to house all three subunits. Subunits 1 and 2 have been installed and operated separately. Subunit 3 has been designed and the purchase orders written. Installation of Subunit 3 is scheduled for completion in March 1980. Operation of the combined bench-scale unit is scheduled for 1981.

ACKNOWLEDGMENT

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DEVELOPMENT STATUS OF THE STEAM-IRON PROCESS FOR HYDROGEN PRODUCTION

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EXTENDED ABSTRACT

INTRODUCTION

The objective of the Steam-Iron development program is to provide an economically attractive and environmentally acceptable method for producing hydrogen from coal. The production of hydrogen is a key step in the conversion of coal to clean-burning synfuels. The Steam-Iron process can be used to produce hydrogen in many chemical conversion processes, including ammonia manufacture, petroleum refining, alcohol manufacture and metallurgical operations. Further Steam-Iron is a cogeneration process in which large amounts of electric power are produced in addition to high-purity hydrogen. This power can be separatel marketed or used to produce liquid hydrogen as an advanced aviation fuel.

PROCESS DESCRIPTION

The Steam-Iron process is based on the chemically reversible reduction and oxidation reactions of iron oxides:

Reduction by Reducing-Gas	K at 1500°F
(1) $Fe_3O_4 + H_2 \rightarrow 3FeO + H_2O$	2.52
(2) $Fe_3O_4 + CO \rightarrow 3FeO + CO_2$	
(3) $FeO + H_2 \rightarrow Fe + H_2O$	
(4) $FeO + CO \rightarrow Fe + CO_2$	0.52
Oxidation by Steam	
(5) $Fe + H_2O \rightarrow FeO + H_2$	1.92
(6) $3FeO + H_2O \rightarrow Fe_3O_4 + H_2$	0.40

These equilibrium constants show that a high reducing-gas conversion is obtain by the reduction of Fe_3O_4, and that a high steam conversion is obtained by the oxidation of Fe. Therefore, high thermodynamic efficiency requires counter-current operation to take advantage of these reactions. The reducing gas must react with FeO before reacting with Fe_3O_4, and the steam must react with FeO before reacting with Fe.

The Steam-Iron process uses elevated pressure, staged countercurrent operation, recycling of the iron ore, and energy recovery to achieve high thermal efficiency and continuous high-purity hydrogen production.

PILOT PLANT DESCRIPTION

The Steam-Iron pilot plant program was initiated in May 1973 under a contract with the Office of Coal Research (later U.S. Department of Energy). The overall objective was to conduct a definitive pilot plant test program to verify the technical and economic feasibility of the continuous production of high-purity hydrogen at elevated pressure and to provide detailed data for the design of commercial plants. A pilot facility, capable of producing 1.1 million SCF of hydrogen per day from 50 ton/day of coal char was designed and built in Chicago.

The steam-iron facility includes equipment to prepare and feed char to the high-pressure reactor system and to process and clean products and wastes. Two principal vessels comprise the reactor system: 1) a producer reactor to make the reducing gas by reacting char with steam and air and 2) a steam-iron reactor in which iron ore is continuously and cyclically reduced by the producer gas and oxidized with steam to produce hydrogen.

Specific program objectives included future integration with the HYGAS® process, which produces substitute natural gas from coal. The Steam-Iron process is especially suited for producing hydrogen for the HYGAS® process because the hydrogen can be fed directly from the oxidation zone (at process temperature and pressure) to the HYGAS® reactor system, and because the partially gasified coal char from a HYGAS® reactor can be used to produce a reducing-gas.

PILOT PLANT OPERATION

Construction of the plant was completed in July 1976. During a 2-year operating program funded by the Department of Energy and the Gas Research Institute, the feasibility of producing hydrogen by the combined, high pressure Steam-Iron process was demonstrated. A total of 20 test runs was completed. First, the three main reactor systems — the slurry heater, the producer reactor, and the steam-iron reactor — were separately tested to establish stable operation and to evaluate the instrumentation and controls. Next integrated operation of these three systems was established, and six consecutive hydrogen-producing tests were conducted to study variables affecting hydrogen production. Test 20, which achieved the longest hydrogen-producing period (130 hours) was terminated on September 30, 1978, marking the end of the contract period. Further development was postponed by DOE for programmatic reasons.

COMMERCIALIZATION

Commercial design options include an ash agglomerating gasifier which allows 98% conversion of the coal and eliminates the need to pretreat caking eastern coal. In addition, recovery of energy from both the spent reducing gas and the hydrogen product gas results in sufficient electric power generation to provide for all process requirements including hydrogen liquefaction, if desired. Because of these advantages, the Steam-Iron process is economically superior to other coal-based hydrogen processes.

We estimate that an additional 1-1/2 to 2 years of pilot plant operation are necessary to establish a sufficient data base for scale-up to commercial desig

THE RELATION BETWEEN METALLURGICAL MICROSTRUCTURE AND THE RESISTANCE TO HYDROGEN EMBRITTLEMENT IN COAL GASIFIER FERROUS ALLOYS

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EXTENDED ABSTRACT

A significant factor determining the sensitivity to hydrogen embrittlement in ferrous alloys is the degree of constitutional instability possessed by the alloy. The majority of ferrous materials of commercial significance possess concentration fluctuations when they are subjected to certain deformation temperatures and degrees of strain. These concentration fluctuations are great enough in most cases to produce clusters, zones, metastable precipitate and even equilibrium precipitate when the materials are strained. The nature and intensity of these strain induced transformations are a function of the degree of strain, the deformation temperature and the strain rate as well as of the composition of the alloy system itself. These strain-induced transformations affect the concomitantly produced dislocation structure.

The fact that ferrous alloys containing carbon (and other carbide forming alloying elements) possess these constitutional instabilities is a primary factor leading to their susceptibility to hydrogen embrittlement. In this regard, the heterogeneity of the dislocation structure (degree of planar array) is determined by the degree of constitutional instability of the alloy. In turn this dislocation distribution determines the ease of the link up of voids formed during heavy plastic deformation and with the hydrogen behaving as an activator or promotor affects the fracture behavior of the alloys. In addition the fracture behavior is also affected in a paramount way by the character of the second phase structure of the ferrous alloys. All multiphased ferrous alloys containing carbon (and other carbide forming alloying elements) possess <u>some</u> susceptibility to hydrogen embrittlement. The embrittling tendency is quite great if the martensite phase is present; even as little as 10% (volume) martensite in the microstructure of steel causes severe susceptibility to hydrogen embrittlement. Lessor degrees of embrittlement are caused by the structures (1) bainite, (2) pearlite and (3) spheroidal cementite with the above listing being the order of embrittlement. It has become apparent that significant resistance to hydrogen embrittlement along with high strength cannot be achieved in ferrous materials utilizing the normal steel metallurgy microstructures of martensite, bainite and pearlite. Instead dispersion type microstructures in conjunction with programmed dislocation arrays and densities must be produced in order to yield high strength steels with a minimum tendency for constitutional instability and a maximum resistance to hydrogen embrittlement.

DESIGN OF HYDROGEN STORAGE MATERIALS

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To be able to treat the design of a hydrogen storáge material as an engineering problem, at least four aspects should be considered:

a) Thermodynamics of the storage process.
b) Kinetics of absorption and desorption.
c) Material's science problems, and
d) Economic considerations.

We write down and discuss equations which characterize a) and b) of the four above mentioned considerations. The science and technology available does not allow the simultaneous optimization of the four problems.

THERMODYNAMICS.

The basic thermodynamic equilibrium is described by the equations recently proposed by Keller, Keller and Baltensperger [1]. The equilibrium between H_2-gas and the hydrogen in the bulk of the storage material is described in terms of a model partition function for hydrogen atoms in the absorbed state for N hydrogen atoms

$$f_N = e^{-\Delta E_a/k_B T} \{ f_{SO} + f_{ST} \}^{XN} \; f_a^{(1-X)N} \quad \left(\text{see [1] for description of each term} \right)$$

which describes the absorption of hydrogen and its distribution among saturated octahedral sites (SO), saturated tetrahedral sites (ST) and molecules absorbed in a region of the material where neighbouring absorbing places are available (a). X is the fraction of the O-sites (and T-sites if these are available) which are occupied.

This model partition function follows the ideas of the cell theories of liquids, which are actually more justified in the present context.

The condition for thermodynamic equilibrium, that the chemical potentials for the hydrogen atomic solution inside and the molecular gas outside are equal, will be fullfilled at a given outside pressure P of the hydrogen containing molecules. In the case of the H_2 + (storage material + XH) system the condition is

$$2(F(\text{inside}) + P(\text{inside}) \times V(\text{inside}) + \Delta E(\text{absorption}))$$
$$= F(H_2, \text{outside}) + P(\text{outside}) \times V(\text{outside}) + \Delta E(2H \rightarrow H_2)$$

The relevant parameters to describe the hydrogen absorbed in the bulk are: the dissociation energy of the H_2 molecule, the reference absorption energy ΔE_a , the association energy of hydrogen atoms inside of the absorber ΔE_{SO} and ΔE_{ST} and the average vibrational frequency of an absorbed hydrogen atom in the saturated condition. A further parameter was introduced to represent the difussion process of the hydrogen in the material, an effective atomic H mass m*. All these parameters can be discussed in terms of the structure and chemical composition of the absorbing material and from this connection the possibility of "designing" a storage material is presented.

KINETICS.

The kinetics of the process is assumed to be dominated by the splitting of the hydrogen molecules at the surface for absorption and the recombination on desorption. This is a classical catalytic problem which we began to consider in Ref. 1 studying the effect of spin density at the surface on this process. In the present paper we assume that the surface has to be catalytic for hydrogen splitting and recombination. We separate the storage problem studied under the model on the previous section from the kinetic problem studied on the basis of the controlling step.

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$SmCo_5$ HYDRIDING KINETICS—THE INVERSE OVERPRESSURE EFFECT[a]

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EXTENDED ABSTRACT

INTRODUCTION

Certain metal alloys absorb large amounts of hydrogen (some with densities greater than that of liquid hydrogen) at relatively low pressures at room temperature. This capability makes them important considerations for hydrogen storage [1]. The function of storage alloys in practical systems is governed extensively by the reaction kinetics as well as the thermodynamics. Reaction rates of hydride systems have been discussed qualitatively by many observers but the high reaction rates make use of the normal pressure-volume methods to obtain good quantitative data very difficult. We have developed a high-pressure hydrogen microbalance [2,3] which is capable of responding to the rapid changes accompanying hydriding. $SmCo_5$ was chosen for this first study because its strong magnetic properties allow corresponding magnetic measurements to be made.

EXPERIMENTAL

Samples of $SmCo_5$ weighing approximately 0.2 grams were placed in the microbalance under 250 psia gaseous hydrogen at 200°C for a few hours to "activate" the specimen. The sample was then cooled to room temperature upon which absorption of hydrogen occurred. Cycling between 250 psia and 15 psia was performed several times to ensure complete activation. Weight gain vs. time measurements were made for the hydriding and dehydriding reactions at several pressures between 88 psia and 233 psia. All dehydriding measurements were performed against a hydrogen pressure of 1.0 atm.

RESULTS AND DISCUSSIONS

The hydriding rate kinetics of $SmCo_5$ can be described by the Johnson-Mehl equation [4-6]:

$$F(t) = 1 - \exp[-(t/\tau)^n], \tag{1}$$

where $F(t)$ is the fraction of the reaction completed at time t,
τ is the reaction rate time constant, and
n is usually an integer or half integer.

This equation can also be written in the form:

$$\ln[1/(1-F(t))]^{1/n} = t/\tau \tag{2}$$

Therefore, a graph of $\ln[1/(1-F(t))]^{1/n}$ vs. t for the value of n that gives a straight line yields τ. The slope of the line is $1/\tau$. The value of n which gave the best line was 2. Thus, the hydriding kinetics show a $(t/\tau)^2$ dependence. Table I shows the time constants for various hydrogen pressures. A plot of $1/\tau$ vs. pressure (Figure 1) shows that τ is proportional to the inverse of the overpressure $(P-P_E)$, and is described by the equation

$$\tau(P) = \tau'/(P-P_E) \tag{3}$$

where P_E is the plateau pressure, and
τ' is a constant.

Therefore Equation 1 becomes:

$$F(t) = 1 - \exp\left[-\left(\frac{t}{\frac{\tau'}{(P-P_E)}}\right)^2\right] \tag{4}$$

The dehydriding rate time constant was measured to be 89.0 sec; however, only slight contamination, such as exposure to poor vacuum conditions, significantly slowed the dehydriding rate.

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TABLE I. $SmCo_5$ HYDRIDING RATE CONSTANTS, τ, AS A FUNCTION OF HYDROGEN PRESSURE

Pressure (psia)	τ (sec)
Hydriding	
233	39.6
202	54.2
170	75.9
150	99.2
133	136
118	205
102	374
95	637
93	886
88	1660
Dehydriding	
15	89.0

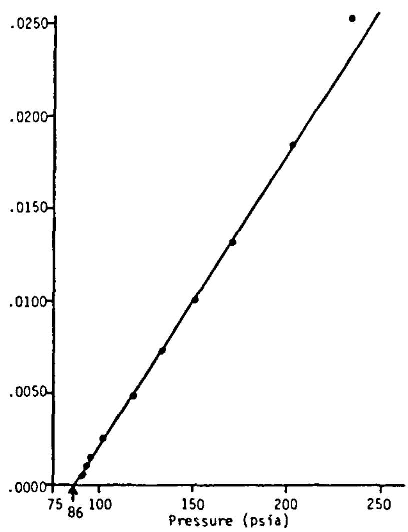

Fig. 1. 1/τ vs. Pressure for $SmCo_5$ Hydriding Rates.

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THERMOCHEMICAL WATER-SPLITTING CYCLES BASED UPON REACTIONS OF CERIUM AND ALKALINE EARTH PHOSPHATES

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EXTENDED ABSTRACT

INTRODUCTION

We recently devised and experimentally confirmed two thermochemical cycles based upon the chemistry of CeO_2 and $CePO_4$. The first of these [1] is outlined by Eqs 1-5, and is capable of splitting CO_2 into CO and oxygen

$$2CeO_2 + 3Na_4P_2O_7 = 2Na_3Ce(PO_4)_2 + 2Na_3PO_4 + 1/2O_2 \qquad T_1 \simeq 800°C \quad (1)$$

$$2Na_3Ce(PO_4)_2 + 3Na_2CO_3 = 2CeO_2 + 4Na_3PO_4 + 2CO_2 + CO \qquad T_2 \simeq 800°C \quad (2)$$

$$2Na_3Ce(PO_4)_2 + 3Na_2CO_3 + H_2O = 2CeO_2 + 4Na_3PO_4 + 3CO_2 + H_2 \qquad T_2' \simeq 800°C \quad (2')$$

$$6Na_3PO_4 + 6CO_2 + 6H_2O = 6Na_2HPO_4 + 6NaHCO_3 \qquad T_3 = 0\text{-}20°C \quad (3)$$

$$6NaHCO_3 = 3Na_2CO_3 + 3CO_2 + 3H_2O \qquad T_4 > 250°C \quad (4)$$

$$6Na_2HPO_4 = 3Na_4P_2O_7 + 3H_2O \qquad T_5 = 270°C \quad (5)$$

as well as splitting water into hydrogen and oxygen. The second of these cycles [2] is outlined by Eqs 6-9, where X=Cl, Br, or I.

$$2CeO_2 + Li_3P_3O_9 = 2CePO_4 + Li_3PO_4 + 1/2O_2 \qquad T_6 \simeq 690°C \quad (6)$$

$$2CePO_4 + 6LiX = 2CeO_2 + 2Li_3PO_4 + 6HX + H_2 \qquad T_7 \simeq 850°C \quad (7)$$

$$2Li_3PO_4 + 6HX = 6LiX + 2H_3PO_4 \qquad T_8 = 25°C \quad (8)$$

$$2H_3PO_4 + Li_3PO_4 = Li_3P_3O_9 + 3H_2O \qquad T_9 > 200°C \quad (9)$$

Thermodynamic calculations indicated that cerium-alkaline earth based thermochemical cycles similar to those shown above might be developed. This paper reports the results of experiments based upon this idea.

RESULTS

The reaction between CeO_2 and $Ba_2P_2O_7$ at 750-1200°C produces O_2 and a barium-cerium double phosphate (Eq 10). The analogous reaction between CeO_2 and $SrHPO_4$ or $Sr_2P_2O_7$ takes place at similar temperatures and also

$$2CeO_2 + 3Ba_2P_2O_7 = 2\text{"}Ba_3Ce(PO_4)_3\text{"} + 1/2O_2 \quad (10)$$

produces an alkaline-earth-cerium double phosphate. The composition for these double phosphates was determined by firing mixtures containing varying amounts of $CePO_4$ with $Ba_3(PO_4)_2$ or $Sr_3(PO_4)_2$; mixtures which contained equimolar amounts of the reactants produced solids whose X-ray powder patterns were identical to those of the solid products of Eq 10. When CeO_2 was fired with $CaHPO_4$ or $Ca_2P_2O_7$, oxygen was evolved at 930-1250°C. The solid products of these reactions are $CePO_4$ and $Ca_3(PO_4)_2$. For all three alkaline earths, 95-100% of the expected oxygen was produced, based upon the stoichiometry indicated in Eq 10.

The '$Ba_3Ce(PO_4)_3$' reacts with $BaCl_2$ and steam at 600-960°C to produce H_2, CeO_2, $Ba_3(PO_4)_2$, and HCl (Eq 11). The solid products of this reaction

$$2\text{"}Ba_3Ce(PO_4)_3\text{"} + 3BaCl_2 + 4H_2O = 2CeO_2 + 3Ba_3(PO_4)_2 + 6HCl + H_2 \quad (11)$$

are difficult to separate, but their treatment with aqueous HCl yields insoluble CeO_2 and $Ba_3(PO_4)_2$, along with soluble $BaCl_2$ and H_3PO_4 (Eq 12).

$$2CeO_2 + 3Ba_3(PO_4)_2 + 6HCl = 2CeO_2 + 2Ba_3(PO_4)_2 + 3BaCl_2 + 2H_3PO_4 \quad (12)$$

The soluble species can then be removed from the insoluble species by simple filtration. Separate experiments showed that treatment of $Ba_3(PO_4)_2$ with aqueous HCl does not produce $BaHPO_4$ or $Ba(H_2PO_4)_2$ in significant quantities at 25°C. When Ba is replaced by Sr, the temperature required for Eq 11 is somewhat lower — 580-850°C. When Ba is replaced by Ca, the temperature required for Eq 11 is significantly lower — 500-800°C. In both cases, the conditions required for Eq 12 are same for Sr and Ca as they are for Ba. Reactions analogous to Eq 9 complete these cycles.

When $CePO_4$ is reacted with $BaCO_3$ at 1200°C, about 5% of the expected CO is produced (see Eq 2) after about 6 hrs. When $CePO_4$ is reacted with $BaCO_3$ in the presence of steam, 80-100% of the expected H_2 is evolved (see Eq 2') in 2 hrs at 700-920°C. Similar reactions take place when Ba is replaced by Sr or Ca. In the case of Ca, the required temperature are higher — 1000-1100°C. We have so far been unable to complete thermochemical cycles based upon these reactions with carbonates because of difficulties in separating the reaction products. For example, all of the products of the treatment of $M_3(PO_4)_2$ with CO_2 and H_2O are insoluble.

SUMMARY

Thermochemical cycles similar to that outlined by Eqs 6-9 have been devised and experimentally confirmed. These cycles are based upon reactions of

CeO_2 with alkaline earth pyrophosphates, which produce oxygen and Ce(III) phosphates. Reactions of Ce(III) phosphates with alkaline earth chlorides and steam produce hydrogen, HCl, CeO_2, and alkaline earth orthophosphates. Treatment of the alkaline earth orthophosphates with HCl yields H_3PO_4, which is reacted with more alkaline earth orthophosphate at >300°C to regenerate the pyrophosphates. Eqs 13-16 summarize these cycles.

$$2CeO_2 + 3M_2P_2O_7 = 2CePO_4 \cdot M_3(PO_4)_2 + 1/2O_2 \quad (M=Ba,Sr,Ca) \tag{13}$$

$$2CePO_4 \cdot M_3(PO_4)_2 + 3MCl_2 + 4H_2O = 2CeO_2 + 3M_3(PO_4)_2 + 6HCl + H_2 \tag{14}$$

$$M_3(PO_4)_2 + 6HCl = 3MCl_2 + 2H_3PO_4 \tag{15}$$

$$2M_3(PO_4)_2 + 2H_3PO_4 = 3M_2P_2O_7 + 3H_2O \tag{16}$$

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THERMOELECTROCHEMICAL HYDROGEN PRODUCTION USING SODIUM CHLORIDE

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ABSTRACT

Three closed-cycle processes for the thermoelectrochemical production of hydrogen from water using sodium chloride are under investigation. The maximum required temperature of 700^{o} C can be achieved by solar energy using various concentration techniques. By means of photovoltaic cells or a solar power station, the required electric power can be obtained.

Recently, many processes for the production of hydrogen by means of a multi-step thermochemical and electrochemical decomposition of water have been proposed in the literature. Many of these processes utilize nonrenewable sources of energy. Most of the used raw materials are very inexpensive and available. In these hybrid cycles, hydrogen is produced in two steps of the five-step water splitting process. The abundant solar radiation can be used as an energy supply for the processes.

Sodium Chloride, originally used, can be purified by adding concentrated hydrochloric acid to a cold saturated aqueous solution of salt. However, better results can be obtained by passing gaseous hydrogen chloride "produced from the cycle" through the salt solution. The impurities remain in the solution while the sodium chloride is precipitated in a very high state of purity. The side reactions of salts contaminated with raw sodium chloride are important to avoid; thus this purification process is a major factor in achieving high efficiencies and yields.

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Sodium Chloride - Mercury Cycle

The first process is the electrolysis of concentrated sodium chloride solution at 85^{o} C to produce hydrogen, chlorine and sodium hydroxide. The second process is the production of hydrogen chloride gas and oxygen from the reaction between chlorine and water. The third process, which is the second step for hydrogen production, is the reaction of the hot hydrochloric acid and mercury. The fourth process is the reaction of the produced sodium hydroxide with mercuric chloride to produce sodium chloride again, water, and mercuric oxide. The fifth process is the thermal decomposition of the mercuric oxide to mercury and oxygen.

Sodium Chloride - Magnetite Cycle

The first two processes are the same as in the sodium chloride-mercury cycle. The third process is the reaction between magnetite and hydrochloric acid to produce iron chloride, water, and chlorine. The fourth process, which is the second step of hydrogen production, is the reaction of iron chloride and water at 680^{o} C to produce magnetite again, hydrogen chloride gas, and hydrogen. The fifth process is the neutralization of the produced sodium hydroxide with hydrochloric acid to produce pure sodium chloride.

Sodium Chloride - Aluminum Cycle

The first two processes are the same as in the Na CL - Hg Cycle, as well as the Na CL - $Fe_2 O_3$ cycle. The third process is the reaction between aluminum and hydrogen chloride gas to generate anhydrous aluminum chloride and hydrogen as the second step of hydrogen production. The fourth process is the electrolysis of molten aluminum chloride at approximately 200^{o} C. This process regenerated aluminum easily. The fifth process is the regeneration of sodium chloride by reaction of the produced sodium hydroxide and hydrochloric acid.

Each of the three cycles can be either a batch or a continuous operation.

One of the difficult problems in thermochemical cycles is often the separation and purification of products and by-products. However, the proposed cycles are quite simple and do not involve difficult separation procedures. For example, the use of a diaphragm, made of asbestos paper, between the cathode and anode helps in the purification of hydrogen and avoids contamination with chlorine during electrolysis of sodium chloride. By filteration, the insoluble mercuric oxide can be separated easily from sodium chloride solution. Oxygen can be separated from hydrogen chloride gas by passing over water. The remaining products which are gaseous and solids separate automatically. Materials of construction for each unit have also been studied. A flow sheet for each reaction step has been made including material and heat balances. The characteristics of these cycles are being evaluated and their efficiencies will be compared with other hybrid cycles.

SESSION 6A

HEAT TRANSFER AND STORAGE III

SEAS: A SYSTEM FOR UNDERSEA STORAGE OF THERMAL ENERGY

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EXTENDED ABSTRACT

Low cost methods of storing medium grade (200→275°C) thermal energy are of great interest for electrical generation and process heat. Thermal energy obtained from hot water or steam is very attractive. Water costs little, is non-toxic, non-degradable, relatively non-corrosive and has high specific heat. However, the high pressure level of hot water systems on land with the associated hazards, requires expensive thick-walled storage vessels preventing extensive use.

Underwater storage appears to be a low cost, safe, and technically feasible method for storing large volumes of hot water. In the SEAS (Storage of Energy at Sea) concept, hot water is stored offshore or in deep lakes at a sufficient depth that the ambient hydrostatic pressure equals or exceeds saturation pressure. Storage containers then need only be thick enough to counteract small pressure differentials due to density differences between hot and cold water, and to keep thermal losses to an acceptable level. As an example, hydrostatic pressure at 300m (990 ft.) permits storage at a temperature of 232°C (451°F) and a pressure of 2.95 Mpa (428 Psi). Such depths can be reached at a substantial number of locations by a transmission line extending 10 Km or less from land (see Fig. 1).

The technical and economic characteristics of four types of storage containers, transmission lines, and pumping and pressure control systems are examined. The storage container types include a flexible insulated bag or diaphragm retained by anchored steel nets, a tank formed from a large rigid ring with a movable insulated lid, and a constant volume rigid tank with a movable inner disc separating two fluids. In each case, hot water is withdrawn from the container at constant temperature. After being used for electrical generation, the cool water product is stored on land. The flexible bag uses wet cell foam such as silicone filled with oil or water, while the rigid tanks can be either double walled prestressed concrete or double walled steel with a middle insulating layer such as oil saturated sand.

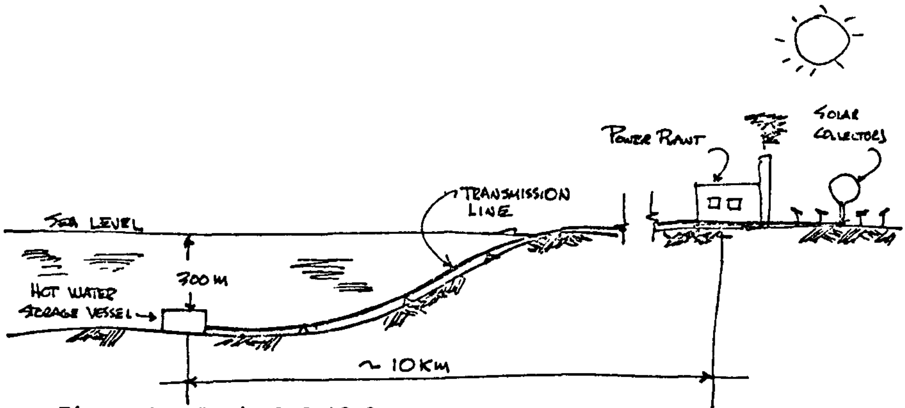

Figure 1. Typical SEAS System

Heat losses are very small in these large tanks. A container of 10^5 m^3 and a temperature of 230°C with only .3 m of insulation would lose heat at the rate of 0.6°C per day. Such a container could supply 2000MW of hot water thermal energy for 10 hours. SEAS storage is adequate for daily or weekly utility load leveling, and with somewhat thicker insulation, for seasonal leveling. The estimated capital cost appears to be at least an order of magnitude lower than previously projected costs of $1,000/$m^3$ in pressure vessels on land. Capital costs of transmission lines appear to be low, based on adjusted costs of existing submerged gas pressure lines. For a unit cost of $500,000/Km a 10 Km line would cost only $2.5/Kw thermal which is small compared to a nuclear plant cost of $200/Kw thermal.

The electrical generation applications examined are use of stored water for feed water heating instead of turbine extraction steam, and use of stored hot water to generate steam for peaking turbines. In the first application, plant electrical output would be increased by approximately 30% to meet peak demands, using the same boiler thermal input when turbine steam is not extracted for feed water heat. In the second application, hot water can be used to generate peaking power at an efficiency of approximately 25%. In either case, the cost of underwater hot water storage appears to be very small, on the order of 1 to 2 mils per KwHr for daily load leveling applications. Hot water can come from intermittent sources such as steam extracted during off-peak periods or from solar collectors.

The lack of cheap storage has been prime factor in holding back the development of solar power. This storage concept should also prove to be useful if floating nuclear plants or solar arrays are developed.

A technical and economic analysis will be made of the SEAS storage system integrated with existing or potential power plant design and its world-wide location potential.

THERMAL ENERGY STORAGE IN AQUIFERS FOR A SOLAR POWER PLANT

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ABSTRACT

It is proposed to develop a thermal energy storage system in a confined aquifer which can be utilized with a solar power plant. The proposed storage system capital cost is estimated to be approximately 0.4 percent of total power plant system capital cost. The proposed operating temperature is 200 C.

The transfer of thermal energy to the aquifer is made with pressurized water injection and withdrawal through a unique system which has been developed. Thermal energy and withdrawal cycles operate on:

1. A daily basis for night time energy requirements.

2. A few day basis for bad weather energy requirements.

3. An annual basis for lower winter insolation requirements.

The aquifer system is conditioned by passing hot water through the aquifer for a period of time prior to aquifer utilization as an energy storage system. This allows the aquifer and aquifer boundaries to reach higher temperatures and allow for high thermal energy recoveries. Analysis indicates that 99 percent of the energy injected can be recovered in a daily cycle, 95 percent plus of the energy injected can be recovered in a few-day cycle and over 80 percent of the energy injected can be recovered in an annual cycle.

Aquifers are water-bearing rocks, sand, gravel, etc., found near or at nominal depths below the soil zone of the earth's surface. For the proposed system, a confined aquifer, one with a confining layer above and below the aquifer, at depths of over 175 meters is required. The top of the aquifer must be a minimum distance below the water table. This

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2. Director of Natural Resources Center; Acting Director of School of Mines and Energy Development.
3. Completing doctorate studies in Mechanical Engineering at The University of Alabama and on leave from the University of Petroleum and Minerals.

minimum distance is required to provide a water head (pressure) sufficient to prevent boiling in the aquifer at the proposed temperature (see attached figure). Thermal energy transfer to the aquifer thermal energy storage is accomplished by transferring hot and warm water to and from the aquifer by a paired system of wells. For each cubic meter of water removed, a cubic meter of water is injected. The net flow to the aquifer is zero. Energy injection and withdrawal is accomplished by reversing flow. Each well will contain a submerged pump and unique controls.

The thermal energy storage system is analyzed in conjunction with a solar power plant system to provide energy during night time, bad weather and the winter low insolation period. A plant system of 40 Mw capacity is utilized for economic analysis. The system consists of a Rankine steam cycle, a two-dimensional parabolic concentrating solar collector system, and the aquifer thermal energy storage system. It is estimated that 1,300,000 m^2 of solar collectors are required for a 20 percent thermodynamic cycle efficiency. The plant capital cost is estimated as:

Installed collector cost based on vender quotation of $20-22/$ft^2$	$300,000,000
Piping based on 25 percent collector cost as estimated by collector vendor	$ 75,000,000
Boilers, steam cycle and generating equipment estimated as $400/kw	$ 16,000,000
Cost for drilling 16 wells at a cost of $100,000 per well	$ 1,600,000
Estimated total	$392,600,000

It should be noted storage capital cost is two percent of the total plant capital cost. The per kilowatt capacity plant capital cost is approximately $10,000/kw. Assuming an interest rate of ten percent, a sinking fund depreciation rate for twenty years with ten percent interest, and 90 percent utilization, the capital cost per kw hr is 14.5 cents.

Economic feasibility for this solar power plant system may occur in the neat future as fuel costs continue to rise. The cost of collectors is expected to decrease with additional solar collector research and production. It is again mentioned that the plant capital storage system capital amounts to only 0.4 percent of the total plant capital cost. This removes a major barrier to solar electric power generation.

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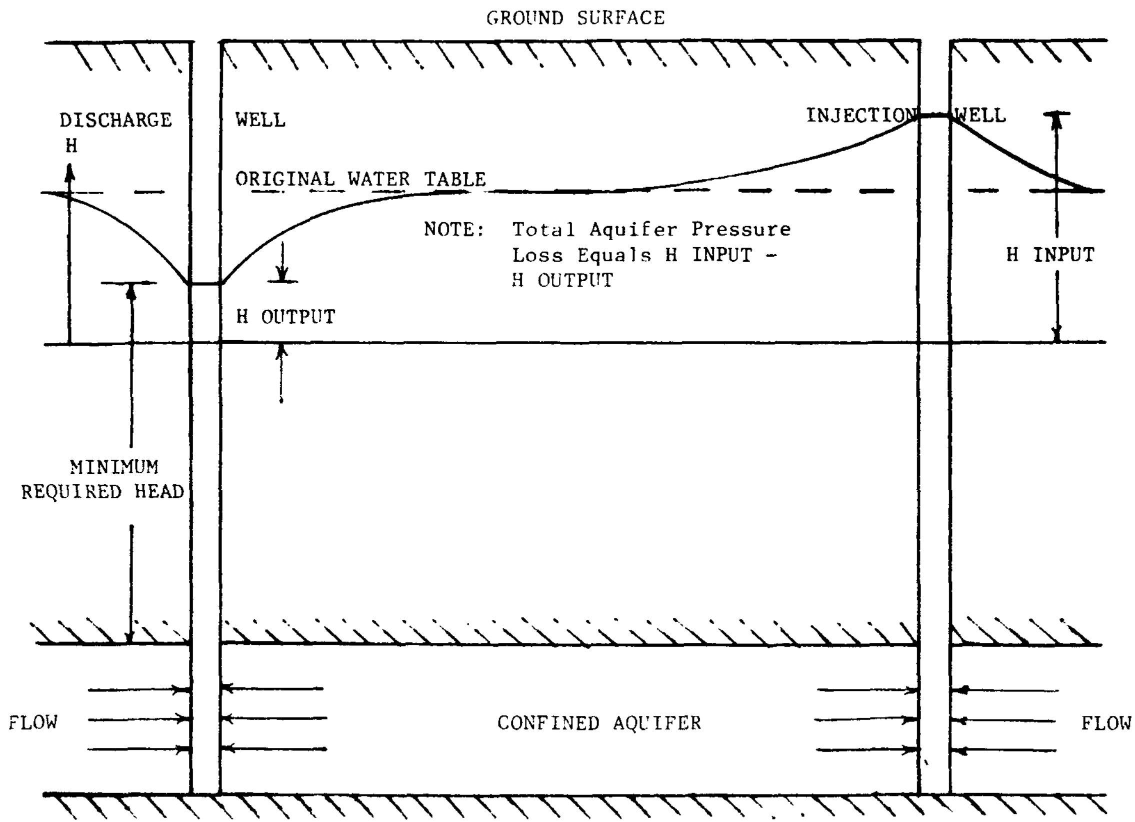

STANDARD WELL PAIR

HEAT TRANSFER IN SOLAR POND

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EXTENDED ABSTRACT

Solar energy received at the surface of a solar pond is partially transmitted to the salt solution beneath and partially lost to the atmosphere. The energy travelling towards the bottom is absorbed in the body of the pond and an appreciable portion of it strikes the blackened bottom. Part os it is conducted back to the solution. The remainder is conducted away towards the earth. As such, the energy transfer in a solar pond is a complex phenomenon and is not very well understood. Weinberger [1], and Rabl and Nielsen [2] have analyzed this phenomenon in ponds of infinite extent under idealized conditions.

In this work an attempt has been made to analytically predict the temperature rise in a solar pond on the basis of a modified heat transfer model. An energy balance has been first attempted in the form of an equation given below

$$I_a = I_i - (I_{Ref} + I_{Rad} + I_{Conv} + I_{Cond})$$

where:

I_a	the rates of energy
I_i	absorbed in the pond
I_{Ref}	incident on pond surface
I_{Rad}	lost by radiation
I_{Conv}	lost by convection
I_{Cond}	lost by conduction

The present model assumes that reflection accounts for 15 to 20% of the losses. Radiation is mainly in the form of sky radiations from the pond surface. Convection loss to the ambient air is the energy which pond fluid absorbs as radiations penetrate through the top convection layer ranging in thickness from 5 to 10 centimeters. The conduction loss from the bottom and side walls could be expressed in terms of average wall temperature, ambient temperature and physical properties of the earth. The energy balance equation has been found to compare well with the experimental results.

The net energy absorbed has been split up into two components. One component being the energy absorbed at the bottom and totally conducted back to pond fluid. This results in some temperature rise. The other component being

the energy absorbed in the pond body as the radiations travel through it affecting some more temperature rise. On the basis of this analysis, an expression has been developed for the temperature rise of the pond fluid as a function of pond depth and the time of exposure of the pond to solar radiations. Due to the complicated nature of the boundary conditions for the heat conduction problem involved, a step by step method of calculation has been adopted.

Theoretical values of temperature rise calculated from the expressions developed from a small solar pond constructed at the University of Roorkee [3]. This solar pond was 4 meters by 4 meters by 1.4 meters in size. It was designed and constructed for the purpose of studying the performance characteristics of a small finite pond. This pond was of brick and cement construction painted black at the bottom and filled with common salt (sodium chloride) solution. Its three zones were a convection zone at the bottom, a constant concentration salt gradient non-convective zone, and a small convective layer at the top. Necessary instrumentation had been provided to record temperature rise of the pond at different depths as a function of time of exposure of the pond to the solar radiations. It was found that the lower convective zone did not last long. In heat transfer analysis, the effect of lower convective zone was not taken into account. These limitations are apparent in the curves which have been drawn to compare the theoretical results with the experimental results.

It has been concluded that the temperature rise in a finite pond could be analytically predicted with fair accuracy from given meteorological and physical system parameters.

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Dup

ENERGY STORAGE TECHNOLOGY - IMPLICATIONS OF LARGE SCALE UTILIZATION*

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EXTENDED ABSTRACT

Environmental impacts resulting from present day utilization of energy generation systems have received considerable attention in recent years. Wastage of both energy and resources have been significant, however, for many of these systems. In one approach to reduce energy consumption and loss, promote resource conservation, minimize foreign resource dependency, increase operational efficiency and reduce costs, consideration has been given by the Department of Energy (DOE) to the development of several major energy storage technologies. These storage technologies, if used on a large scale, are projected to have a number of environmental impacts, not all, of course, necessarily adverse. Nevertheless, these impacts must be assessed so that appropriate environmental control technology, where deemed necessary, can be developed on a schedule compatible with the development of the specific energy storage technology. To assist the Office of Environment of the DOE in the timely development of such control technology, a number of environmental assessment programs have been conducted at the national laboratories including the Los Alamos Scientific Laboratory (LASL) over the past several years. Environmental impacts for several energy storages technologies have been identified. State-of-the-art control technology options were similarly identified. Recommendations for research and development on new control technology were made where present controls were either deemed inadequate or non-existent. In addition, the most recent study included a search for new applications, i.e., applications other than those directly associated with the electric utility industry. The identification of these was considered important insofar that new and significant environmental impacts specifically related to the new application would thus be identified. Finally, where possible, an estimate of the additional cost to the energy storage system or to the end product due to environmental control technology implementation, was made.

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Specifically, the energy storage technologies under study included: advanced lead-acid battery, compressed air, underground pumped hydroelectric, flywheel, superconducting magnetic energy and various thermal systems (sensible, latent heat and reversible chemical reaction). In addition, a preliminary study was conducted on fuel cell technology. Although not strictly classified as an energy storage system, fuel cells in conjunction with product recycling units can serve an energy storage function. Of these systems, only above-ground pumped hydroelectric has been used on a large scale. Lead-acid battery, flywheel and sensible heat systems have been used on individual and small-scale systems.

A very large number of potential environmental impacts can bé identified for all of these technologies. However, not all are of primary importance nor will many necessarily come into existence. For example, those impacts associated with the preoperational phase (usually construction) have a certain degree of commonality for all technologies and are for the most part temporary although some are indeed significant at the time. Similarly, impacts associated with decommissioning have much in common. The latest study emphasizes those impacts associated with routine operation.

A table of those major environmental impacts requiring further research and development on control technology and other relevant information is presented below. The information listed has been taken from a recently completed study at LASL. Additional environmental impacts and available control technology will be discussed in detail.

TABLE 1

MAJOR ENVIRONMENTAL IMPACTS FOR ENERGY STORAGE TECHNOLOGIES

Storage Technology	Operation	Affected Environment	Impactor	Control Technology	Control Technology R&D
Advanced Lead-Acid Battery	Normal	Air Land	Stibine, hydrogen, Acid fumes	Scrubbing, Dilution and Venting Land-fill disposal	Stibine detection instrumentation, Stibine scrubber
	Excursion (fire, acid spill)	Air, Land, Water	Noxious gases, Particulates	Scrubbing, Filtration Venting	
Underground Pumped Hydroelectric	Normal	Land, Water, Biosystems	Turbomachinery, Turbidity	Water Treatment, Filtration	Fracture detection instrumentation
	Excursion (structural failure)	Land	Fracture and Wall Collapse, Flooding	Stabilization, Sealants, Diversion	
Compressed Air	Normal	Air, Land, Noise Biosystems	Turbomachinery, Cyclic Stress, Contamination	Acoustic Design, Siting	Fracture detection instrumentation
	Excursion (structural failure)	Air, Land	Fracture and Wall Collapse	Stabilization, Sealants	
Flywheel	Normal	Land, Noise	None	Design	Possible microvibration detection instrumentation, Design
	Excursion (structural failure)	Land, Noise	Rotor disruptive failure	Design	
Superconducting Magnet	Normal	Land, Biosystems	Magnetic Field, Cyclic Stress	Distance, Structure Reinforcement	Bioeffects of magnetic fields, fracture detection instrumention
	Excursion (structural failure, explosion)	Land	Fracture and Wall Collapse	Stabilization	
Thermal* Sensible, Latent Heat, Reversible Chemical Reaction	Normal	Air, Land, Water, Biosystems	Leakage	Scrubbing, Dilution, Filtration Land-fill disposal	Leak detection instrumentation
	Excursion (explosion, leakage	Air, Land, Water	Chemical and solution releases	Scrubbing, Land-fill disposal	
Fuel Cell	Normal	Air, Land	Electrolyte disposal	Neutralization, Land-fill disposal	None
	Excursion (fire, leakage)	Air, Land	High temperature chemical release	Neutralization, Land-fill disposal	

*Aquifer thermal storage has some unique impacts somewhat similar to aquifer compressed air storage

NUMERICAL RESOLUTION OF THE HEAT TRANSFER EQUATIONS IN A LATENT HEAT SOLAR ENERGY STORAGE SYSTEM

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EXTENDED ABSTRACT

INTRODUCTION

The numerical method presented in this paper allows the calculation of the temperature distribution and liquid solid interface progression in a solar energy storage system, constituted by a phase-change material. The main characteristics of the simulated system are similar to the reference experimental set. The incident radiation flow is directly absorbed by the upper face of the storage medium through a double glazing. The energy is recovered by natural convective and radiative exchange between the bottom of the storage system and the ambient air.

PHYSICAL MODEL

The physical properties of the medium are taken to be the average values of the ones of an industrial paraffin - wax. The melting point is 51°C and the fusion latent heat 160 J/g. The thermal conductivity k and heat capacity C_p of both liquid and solid phases are assumed to be constant : $k_L = k_S = 0.21$ W/m°C

$$C_{pL} = C_{pS} = 1.7 \text{ J/g°C}$$

We will neglect in this approach the change in density occuring in the melting process.

As in the experiments, the radiation flow is constant in direction and intensity, normal to the collection surface. So, the absorption and emission factors, integrated on the emission spectrum of the source will not be time-dependent. The model involves transmission of the radiation in the semi-transparent liquid phase and the residual transmitted flow is assumed to be entirely absorbed at the liquid solid separation. The heat propagation in the system is one dimensional and the heat loss coefficients on both upper and higher sides are constant.

METHODS OF RESOLUTION

In the general case, the system presents both liquid and solid phases. The heat transfer equation in the liquid phase includes a radiation transmission term while the heat propagation in the solid phase is purely conductive. The boundary conditions represent the heat exchange with the ambient air and the flow continuity condition at the interface relates the latent-heat absorption to the displacement of the liquid-solid separation.

The non-linear set of coupled differential equations is solved by an iterative finite difference scheme using an implicit method of discretization. A previous subroutine computes the system of equations until the surface reaches the melting point. Then the main program resolving the general two phase problem is used.

The computation gives the evolution of the temperature distribution in the slab over a 8 hour period and of the progression of the liquid depth.

SENSIBILITY OF THE SYSTEM TO THE VARIATION OF COEFFICIENTS

This program enables us to check the thermal response of the system in various conditions.
The influence of the variations is analyzed for various parameters : thermal conductivity, global surface absorptivity, heat loss coefficients, initial temperature, thickness of the slab and radiation intensity. The comparison criteria are the evolution of the surface temperature, the temperature distribution in the slab and the depth of liquid.

On the basis of this study, fitting techniques can be established to evaluate the order of unknown coefficients of the system in experimental conditions of magnitude.

CONCLUSION

The presented model allows the resolution of a complex problem of radiation and conduction heat-transfer in a phase- change material with obvious applications to solar heat storage systems. Different PCM can easily be compared on this bases. Such storage systems can be optimized as far as their geometry and temperature regulation level are concerned.

ADVANCED SOLAR THERMAL STORAGE MEDIUM TEST DATA AND ANALYSIS

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ABSTRACT

The primary objective of this paper is to present a comparative study of the experimental data of heat transfer and heat storage characteristics of a solar thermal energy storage bed utalizing containerized water, fused salt, and rocks as storage mediums. This experimental investigation was initiated to find new usable heat intensive solar thermal storage device other than rock storage and water tank which have been the basic storage use thus far. To serve this need four different sizes of soup cans filled with water were tested. These cans were stacked in a chamber in three different arrangements - vertical, horizontal, and random. Air is used as tranfer medium for charging and discharge modes at three different mass flow rates and inlet air temperatures respectively. These results were analyzed and compared, which show that a vertical stacking and medium size cans have better heat transfer characteristics. A similar experimental study will be done with three different sizes of plastic jars (1 to 2 liter) filled with phase change material. These results will be compared with the containerized water and rocks test results acquired earlier under a similar test environment. These types of containerized fluid and salt thermal storage medium have a lower pressure drop and volume requirements and higher heat transfer and heat content values than other usual types; also these do not need any special type of storage chamber or heat exchange device. This containerization also allows the storage chamber to be horizontal or vertical with respect to the air flow. The test results and analysis thus far show that this type or storage device will be well suited for use with solar air systems for space and hot water heating in both active and passive systems.

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*The author is the principal investigator of a NASA/MSFC grant No. NSG 8041 "Parametric Study of Thermal Storage Containing Rocks or Fluid Filled Cans for Solar Heating and Cooling." This paper presents some test data produced for this grant.

DOMESTIC SOLAR WATER PREHEATING VERSUS SOLAR WATER HEATING: AN ECONOMIC EVALUATION

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EXTENDED ABSTRACT

Life cycle cost analysis of solar water heating in Brasil indicates that the payback period can be 5-7 years when residential electricity (at US$0.07/$kWh_e$) is the alternative conventional energy, increasing yearly at a rate of 2.5%. The above figures assume a lifetime of 10 years for the equipment and a discount rate of 6% a year. The payback period can be 7-9 years when gas (at US$0.03/$kWh_{th}$) is the alternative conventional energy, increasing yearly at a rate of 5%.

Market penetration studies show that the widespread use of solar water heaters faces the barrier of high initial investment. Although government incentives and/or low interest rates, and long term financing conditions could help to overcome this difficulty, it has been learnt from a survey carried on recently in São Paulo, Brasil that only a small percentage of the population is willing to pay US$900-1300 for a domestic size solar water. Table 1 shows the relationship between the willingness of people in acquiring the solar water heater and the price of the equipment.

TABLE 1. ACQUISITION OF SOLAR WATER HEATERS IN SÃO PAULO, BRASIL

Price range		Percent of Population
up to	US$150	36.3
US$150	US$350	14.0
US$350	US$500	5.3
US$500	US$900	2.0
More than	US$900	1.7
Not interested in buying		33.7
No answer		7.0

Thus, a cost reduction of the solar water heater has the potential of significantly improve the market penetration of such equipments.

Domestic hot water utilization in Brasil is basically for bathing purposes at temperatures not higher than 40-50°C. A small percentage of the domestic hot water is consumed in kitchens at 60°C (i.e. dishwashing). Therefore, any cost reduction of systems operating in the 40-50°C range could significantly improve the market penetration for solar water heaters.

As well known, the efficiency of solar collectors is higher for small collector-to-ambient temperature differences. Solar collectors, therefore, operate at high efficiencies in most regions of Brasil, where the ambient temperature is usually in the 20-30°C range. Table 2 shows the yearly average climatic data for the coldest main cities in Brasil, where the market potential for solar energy utilization is greater.

TABLE 2. CLIMATIC DATA IN BRASIL

City	Average Temperature (°C)	Incident Radiation (kWh/m^2.year)
Brasília	21.4	1934
Belo Horizonte	21.5	1896
Curitiba	17.6	1656
Rio de Janeiro	23.7	1602
Porto Alegre	20.1	1594
Florianópolis	20.8	1495
São Paulo	20.0	1674

Single glazed collectors are usually chosen for this type of application and operate more efficiently than double glazed collectors in most Brasilian cities for the 40-50°C temperature range required for domestic hot water systems, which are marketed at an average price of US$250 per square meter of collector.

Domestic hot water systems utilizing unglazed collectors of the plastic type as in swimming pool heaters, could be marketed at US$150 per square meter of collectors and if adequate for domestic water heating could reduce considerably the payback period for the solar water heater and thus improve the market penetration of such equipments.

This paper uses an accepted simulation model (f-chart) for predicting the solar contribution to the hot water load, using as a reference single glazed collectors operating in systems with 75 liters of consumption water per square meter of collectors and calculates the collector area required for the system when operating with unglazed collectors at the same solar contribution. Table 3 presents the results of such calculations for the 40-60°C range of hot water temperature.

This paper, thus, shows that if hot water is required at less than 60°C, the use of unglazed collectors can be cost effective, even though the collector area required is slightly larger than for single glazed collectors at the same solar contribution. A total system cost reduction by a factor of 1.5 can be achieved in many cold cities of Brasil if hot water is required at 45°C (bathing purposes). As a consequence, the payback period can be substantially reduced and the market penetration of solar water heater becomes greater.

TABLE 3. AREA RATIO FOR SAME SOLAR CONTRIBUTION FOR DIFFERENT WATER TEMPERATURE, FOR DIFFERENT CITIES

City	HOT WATER TEMPERATURE									
	40°C		45°C		50°C		55°C		60°C	
	SC	AR	SC	AR	SC	AR	SC	AR	SC	AR
Brasília	0.91	0.98	0.81	1.09	0.71	1.18	0.63	1.25	0.56	1.31
Belo Horizonte	0.90	0.97	0.80	1.09	0.71	1.17	0.63	1.25	0.56	1.30
Curitiba	0.77	1.16	0.67	1.25	0.59	1.33	0.52	1.39	0.46	1.44
Rio de Janeiro	0.82	0.85	0.70	0.98	0.61	1.08	0.53	1.17	0.46	1.25
Porto Alegre	0.77	1.03	0.66	1.14	0.57	1.23	0.50	1.30	0.44	1.37
Florianópolis	0.74	1.00	0.63	1.11	0.54	1.20	0.47	1.28	0.41	1.35
São Paulo	0.80	1.04	0.70	1.15	0.61	1.23	0.53	1.29	0.47	1.36

SC - Solar contribution

AR - Unglazed collector to single glazed collector area ratio for the same solar contribution

Finally an economic analysis of solar heated water is carried out under different conditions for different cities in Brasil.

SESSION 6B

SOLAR ENERGY ECONOMICS

COMPARATIVE ECONOMICS OF SMALL SOLAR THERMAL ELECTRIC POWER SYSTEMS

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EXTENDED ABSTRACT

INTRODUCTION

Numerous concepts have been proposed for use as small solar thermal electric power systems, generating electricity in the 1-10 MWe range. These concepts differ primarily in the type of solar collector and the energy conversion cycles used. Estimates of system capital cost; i.e., the initial investment required to install the plant, are valuable in establishing which concepts are more economically viable. To permit comparisons, cost estimates must be developed from a common or normalized costing basis (i.e., uniform material/equipment unit costs, methodologies and assumptions). This paper contains "normalized" cost estimates for the principal small solar thermal electric power system concepts. Estimates were developed as part of an overall effort to identify, evaluate, and rank (based on economic, technical, and environmental performance) alternative solar thermal conversion concepts that have the potential for achieving initial commercialization as small electric power generation systems by the mid-1980's. The study was conducted by Battelle, Pacific Northwest Laboratory for the Division of Central Solar Technology, the Department of Energy.

CONCEPTS ANALYZED

Concepts are distinguished on the basis of the generic collector type and power conversion cycle used. Collector systems included two-axis tracking concepts (point focus), one-axis tracking concepts (line focus), and non-tracking concepts. Power conversion options considered were by Rankine, Brayton, or Stirling cycle engines. The 10 concepts analyzed are:

- Point Focus Concentrator/Central Receiver/Rankine Cycle (PFCR/R)
- Point Focus Concentrator/Central Receiver/Brayton Cycle (PFCR/B)
- Point Focus Concentrator/Distributed Receiver/Rankine Cycle (PFDR/R)
- Point Focus Cencentrator/Distributed Receiver/Brayton Cycle (PFDR/B)
- Point Focus Concentrator/Distributed Receiver/Stirling Cycle (PFDR/S)

- Fixed Mirror Concentrator/Distributed Focus Receiver/Ranking Cycle (FMDF)
- Line Focus Concentrator Central Receiver/Rankine Cycle (LFCR)
- Line Focus Concentrator/Distributed Receiver/Rankine Cycle (LFDR-TC)
- Line Focus Fixed Concentrator/Distributed Receiver/Rankine Cycle (LFDR-TR)
- Low Concentration Concentrator/Distributed Receiver/Rankine Cycle (LCNT)

APPROACH

Capital cost estimates were determined for each plant component at various plant configurations. These cost estimates were used to develop a cost estimate scaling relation (CESR) for each component. A CESR is a mathematical expression which relates how component costs will change as plant layout and design configurations vary. Cost estimating relationships are then implemented in SOLSTEP, a computer simulation model described in greater detail elsewhere[1]. SOLSTEP calculates plant performance and estimates capital costs for alternative plant design points, obtaining least cost design configurations to yield a specific plant capacity factor.

RESULTS

Capital investment costs for 5 MWe solar thermal power plants at 0.4 capacity factor were found to range from approximately $2000-$3000/kW for the 10 concepts analyzed. Capital investment costs show a marked sensitivity to plant capacity factor and power level. Increasing the capacity factor from 0.4 to 0.7 for 5 MWe plants requires a 50-100 percent increase in capital investment costs. Decreasing plant power level from 5 MWe to 1 MWe also requires substantial capital investment cost increases on a $/kW basis. Effects of plant power level and capacity factor on capital investment costs vary substantially between concepts, showing that a comparison of concepts for a specific plant will not necessarily be valid at other capacity factors or power levels. In general, capital investment costs achieved by point focus concepts were lower than those achieved by line focus and nontracking concepts.

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SOLAR STANDARDS AND TESTING ACTIVITIES IN DEVELOPED AND DEVELOPING COUNTRIES

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EXTENDED ABSTRACT

The recent development of solar energy as one of the national energy sources in the United States originates from the Solar Heating and Cooling Demonstration Act which was passed by the U.S. Congress in September, 1974. The purpose of this act is, "to provide for the early development and commercial demonstration of the technology of solar heating and combined solar heating and cooling systems." The same act also mandates development of, "interim performance criteria for solar heating and combined solar heating and cooling components and systems to be used in residential dwellings." In consequence of this act, the federal government became committed to supporting the development of solar energy and to providing the proper incentives. This commitment is visible on the base of the increase in funds allocated to solar energy research, development, and demonstration. Also, the federal tax credit incentives which were passed 16 October 1978 will certainly contribute to the growth of solar industry.

The need for a voluntary solar standards process in the U.S. materialized in order to provide incentives for this new solar industry, introduce consensus quality and performance levels, set up a basis of comparison for various products, and build up consumer confidence. That process, as illustrated in Figure 1, may take up to several years before a new standard is introduced as an American National Standard [1]. At the present time two of the solar standards

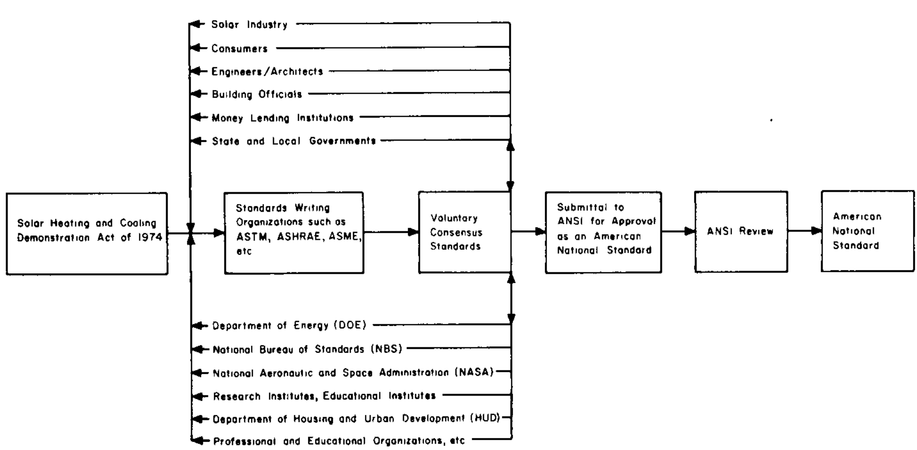

Figure 1. Solar Standards Development Process [1]

have already become American National Standards. They are ASHRAE 93-77, "Method of Testing to Determine Thermal Performance of Solar Collectors" which has the ANSI designation B198.1-1977, and ASHRAE 94.1-77, "Method of Testing Storage Devices Based on Thermal Performance" which has the ANSI designation B199.1-1977. Solar standardization activities are also in progress in Europe and elsewhere. The Commission of the European Communities (CEC) has prepared the draft of documents for future standards entitled "Recommendation for Solar Collector Test Methods" and "Standard Procedures for Qualification Approval of Terrestrial Photovoltaic Modules" [2]. Some solar testing activities are being conducted in the CEC Joint Research Center in Ispra, Italy. Solar standards and testing procedures are being introduced by individual countries or organizations as well. In Germany the Bundesverband Solarenergie (BSE) promulgates Guidelines and Directions for Determining the Usability of Solar Collectors [3]. In France, testing of solar domestic hot water systems and some standardization activities associated with it are taking place in a research center of Comité Scientifique et Technique de l'Industrie du Chauffage, de la Ventilation et du Conditionnement d'Air in Saint Rémy-lès-Chevreuses. In June, 1979 Australia proposed the establishment of a new Technical Committee on Solar Standards within the International Standardization Organization (ISO) located in Geneva, Switzerland.

In the United States there are at the present time well over thirty institutions performing testing of solar equipment. These institutions, of which one of the first was the Laboratory of Solar Energy and Energy Conversion at the University of Florida in Gainesville, Florida, mainly test the thermal performance of solar collectors following ASHRAE 93-77 [4] or NBSIR 78-1305A [5]. Some of them also perform other types of testing. To mention only a few, testing of solar materials is done by Sandia Laboratories in Albuquerque, New Mexico; White Sands Missile Range, New Mexico; Georgia Institute of Technology in Atlanta, Georgia; Boeing Company in Seattle, Washington; Desert Sunshine Exposure Test, Inc. in Phoenix, Arizona; Approved Engineering Test Laboratories in Los Angeles, California. Testing of solar systems is done at Sandia Laboratories in Albuquerque, New Mexico and Wyle Laboratories in Huntsville, Alabama. Environmental testing of photovoltaic cells is performed at Jet Propulsion Laboratory in Pasadena, California and at Boeing Company in Seattle, Washington. I-V testing of photovoltaic cells is carried out at New Mexico State University, Las Cruces, New Mexico; Desert Sunshine Exposure Test, Inc., in Phoenix, Arizona; Jet Propulsion Laboratory in Pasadena, California; Wyle Laboratories in Huntsville, Alabama; Boeing Company in Seattle, Washington, and Sandia Laboratories in Albuquerque, New Mexico. Testing of heat storage devices is executed at the National Bureau of Standards in Gaithersburg, Maryland, and at Desert Sunshine Exposure Test, Inc., in Phoenix, Arizona. Testing of wind turbines is performed by Rockwell International (Rocky Flat Wind Testing Facility) in Rocky Flat, Colorado, and by Vought Corporation in Dallas, Texas. Testing of packaged, domestic type solar water heating systems is done on an experimental basis by the National Bureau of Standards in

Gaithersburg, Maryland, and is planned to be performed following the document ASHRAE 95P [6] at New Mexico State University in the near future under NASA management.

The development of this type of testing capability in addition to solar collector testing is planned at the Florida Solar Energy Center in Cape Canaveral, Florida and is also planned at Desert Sunshine Exposure Test, Inc. in Phoenix, Arizona in addition to current testing activities. The expected NASA testing program of packaged solar water heating systems will be similar to the already successful DOE program of testing flat-plate collectors in which the following eight laboratories were participating: New Mexico State University/Physical Science Laboratory, Florida Solar Energy Center, Desert Sunshine Exposure Test, Inc., University of Florida, Lockheed Missile and Space Company, Wyle Laboratories, Boeing Company, Approved Engineering Test Laboratories. Figures 2 and 3 show schematic diagrams of the flat-plate water and air collector testing stands at New Mexico State University/Physical Science Laboratory. So far this facility is also the only one in the U.S. performing thermal performance testing for radiative cooling flat-plate collectors [7].

The paper will present a detailed description of testing being performed at the New Mexico State University/Physical Science Laboratory and of testing facilities of other institutions, and it will as well present the status of standards and testing in other developed and developing countries.

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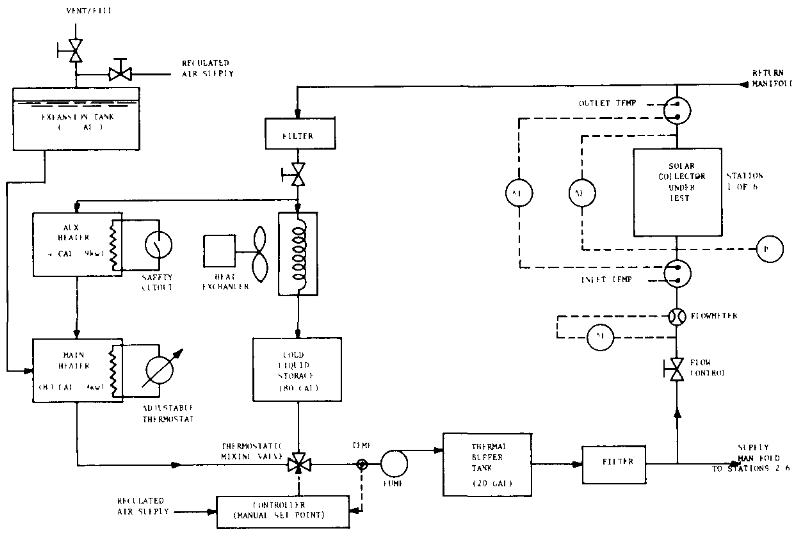

Figure 2. Schematic Diagram of Flat-Plate Water Collectors Testing Stand at NMSU/PSL.

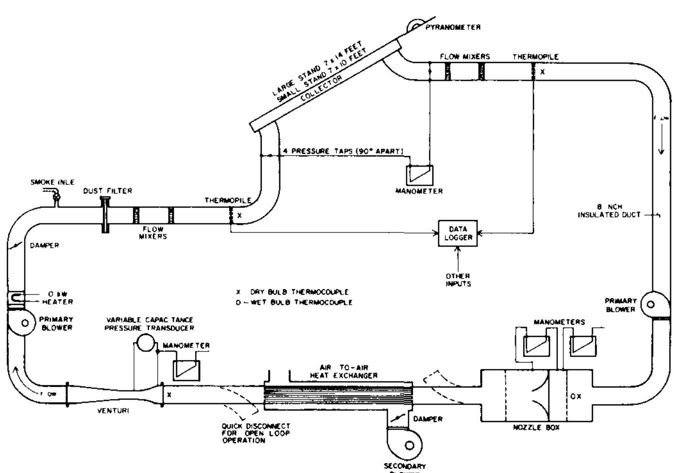

Figure 3. Schematic Diagram of Flat-Plate Air Collectors Testing Stand at NMSU/PSL.

THE SOAR [SOLAR ASSISTED REACTOR] POWER SYSTEM

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EXTENDED ABSTRACT

At present, nuclear or coal plants are the only options for increasing US electrical capacity. Several decades will be required to develop commercial power plants based on pure solar or fusion inputs. Solar energy appears to have practical, near term potential as a supplementary energy source for hybrid power plants in which the main input is nuclear or coal energy. Low and intermediate temperature solar collectors can supply feedwater heat and/ or reheat steam after expansion in a high pressure turbine. This approach is the basis for the SOAR [Solar Assisted Reactor] concept for LWRs. This concept will increase total power output and extend uranium utilization, i. e., kWh(e) per unit amount of fuel consumed.

The Comanche Peak nuclear plant selected for this study represents reasonably current LWR technology. [1] It raises 15,900,000 lb/h of saturated steam at 970 psia, with 90% flowing to the HP turbine and the balance used to reheat the HP turbine exhaust. Six stages of feedwater preheaters is assumed to be replaced by solar energy in a stepwise amnner, starting with the lowest temperature heater and proceeding to the highest temperature feedwater heater. Finally, the reheater was assumed to be replaced by energy from a solar collector. At each step the heat balance diagram was redetermined in detail to ensure thermodynamic consistency.

Figure 1 shows the flow sheet with all feedwater heaters and the steam reheater receiving their energy from solar sources. Plant output increases from the original 1.21 x 10^3 MW(e), for the same thermal power in the reactor core, equivalent to 7400 BTU-kWh based on nuclear fuel usage.

Figure 2 shows the increased plant output and the overall plant efficiency (fraction of ideal Carnot) for the hybrid plants plotted vs. the stepwise incremental solar energy addition. [Carnot efficiency is separately calculated for each thermal input, and then appropriately averaged.] If solar energy is used in heater No. 6, the lowest temperature feedwater heater, the plant capacity increase is negligible. Use of solar energy in heaters No. 6 and No. 5 increases plant output by 3%. Further solar energy addition increases both plant capacity and efficiency above their original design values.

The almost 40% increase in plant electrical output if solar heat is used for all feedwater heat and reheat, is very impressive. An additional 440 MW(e) is produced from a 1600 NW(th) solar input, with a marginal efficiency of 440/1600 or 28%, at a relatively low average temperature of 380 F for the added solar energy. The high efficiency solar utilization is shown in Fig. 2 by the increasing fraction of Carnot. Thermodynamically, it is more efficient to supply sensible feedwater heat from a set of solar collectors

closely matched in temperature to the demand level, rather than to extract steam.

The intermittent solar input requires a practical operating scenario if thermal storage is not used. Since day loads are higher than night loads, most of the increased output can probably be used on the grid. The remaining portion could be accommodated by trimming extraction flow and reactor power when solar energy is available. Alternatively, the extra capacity when the sun shines could electrolyze water to generate hydrogen for synthetic fuels and/or H_2 fuel cells for distributed electrical generation.

The hardware required, aside from solar collectors, involves simple modifications to the feedwater heater system. The high pressure turbine would have to be adapted to handle an additional 9% flow when the reheater is supplied by solar sources. In new plants, the turbine can be designed for this varying flow; a small additional HP turbine may be necessary in retrofitted plants.

Equipment or equipment modification costs have not been estimated for the increased plant capacity (440 MW(e)), but they should be much less than the per kW costs of a new LWR similar to Comanche Peak. Solar collectors will be the major part of the added cost for the SOAR system. For $\$100/m^2$, which appears achievable for the relatively low temperature requirements, capital charges on collectors for a SOAR plant are 30 mils/kWh(e), assuming an annually averaged solar insolation of 0.25 kW(th)/m^2, 28% marginal efficiency, 15% fixed charges, and a plant factor of 0.8. This is comparable to the power costs for new LWR plants. The SOAR concept can be retrofitted to existing LWR plants, as well as applied to new ones. Land area around LWR's appears adequate for solar collection.

In conclusion, use of solar energy for feedwater and steam reheating in hybrid LWR/solar plants should considerably increase plant output with minimum additional equipment requirements, besides the solar collectors, and very good thermodynamic utilization of the added solar energy.

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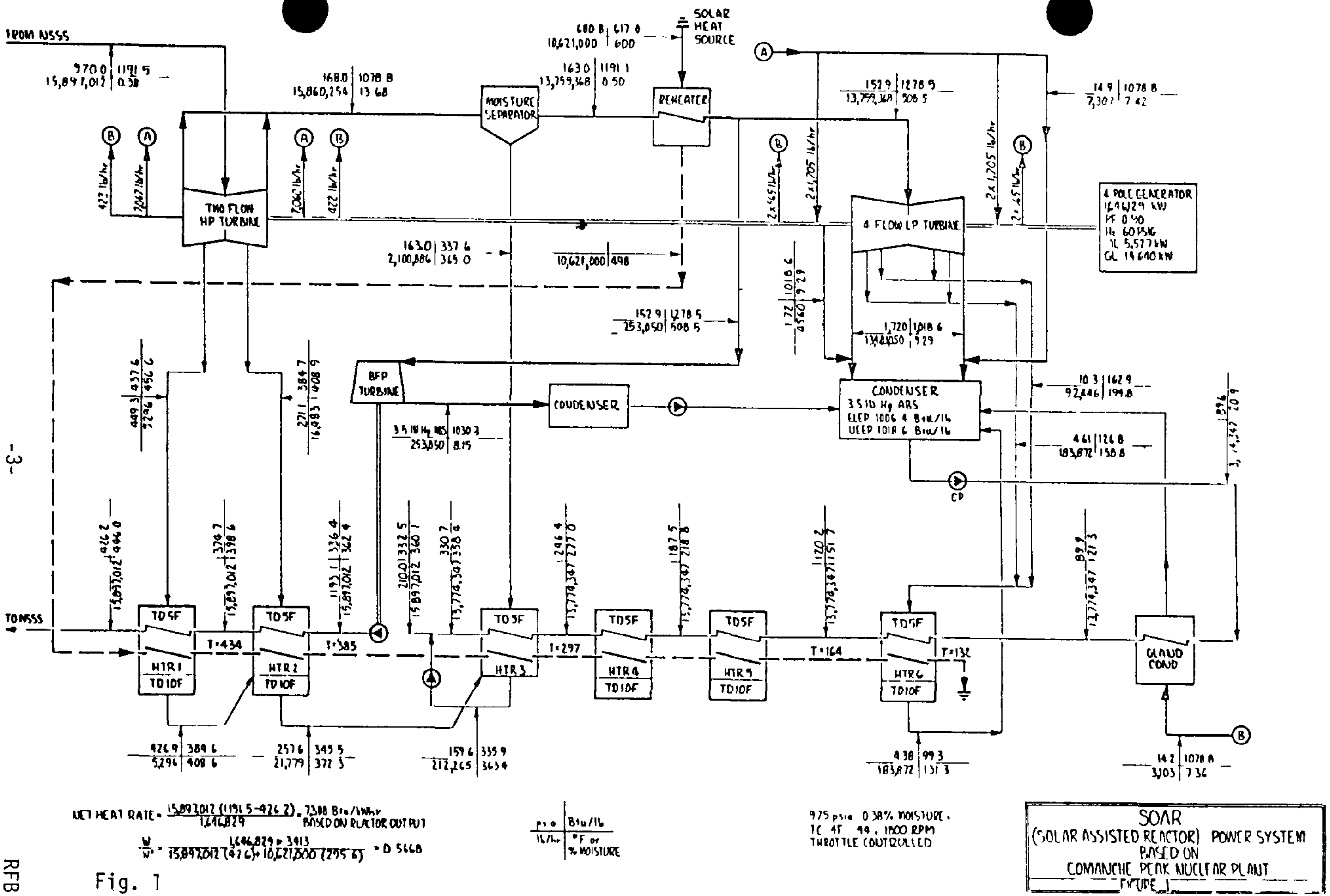
FROM NSSS
SOLAR HEAT SOURCE
MOISTURE SEPARATOR
REHEATER
TWO FLOW HP TURBINE
4 FLOW LP TURBINE
4 POLE GENERATOR
BFP TURBINE
CONDENSER
CONDENSER
3.5 IN Hg ABS
CP
TO NSSS
TDSF
HTR 1
TD10F
HTR 2
HTR 3
HTR 4
HTR 5
HTR 6
GLAND COND
T=434
T=385
T=297
T=164
T=132
NET HEAT RATE = 15,897,012 (1191.5 - 426.2) / 1,646,829 = 7388 Btu/kWhr BASED ON REACTOR OUTPUT
psia | Btu/lb
lb/hr | °F or % MOISTURE
975 psia 0.38% MOISTURE
THROTTLE CONTROLLED
SOAR
(SOLAR ASSISTED REACTOR) POWER SYSTEM
BASED ON
COMANCHE PEAK NUCLEAR PLANT
FIGURE 1

Fig. 1

RFB

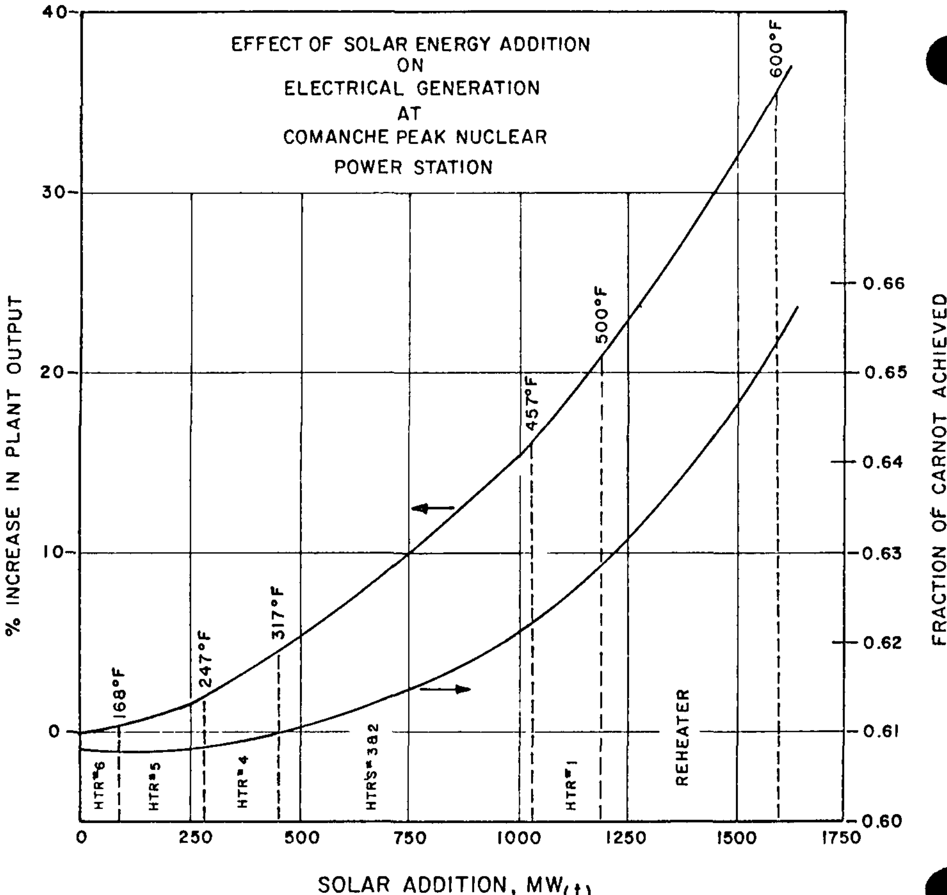
EFFECT OF SOLAR ENERGY ADDITION
ON
ELECTRICAL GENERATION
AT
COMANCHE PEAK NUCLEAR
POWER STATION
% INCREASE IN PLANT OUTPUT
FRACTION OF CARNOT ACHIEVED
SOLAR ADDITION, MW(t)
0
10
20
30
40
0.60
0.61
0.62
0.63
0.64
0.65
0.66
0
250
500
750
1000
1250
1500
1750
168°F
247°F
317°F
457°F
500°F
600°F
HTR#6
HTR#5
HTR#4
HTR'S#3&2
HTR#1
REHEATER

Fig. 2

APPLICATION OF SIMPLE ARIMA MODELS WITH RESPECTIVELY CONSTANT AND SEASONAL PARAMETERS TO SOLAR METEOROLOGY

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EXTENDED ABSTRACT

We have tested some models for the daily irradiation on three typical sites : a temperate one (Trappes), an equatorial one (Huallao) and a mediterranean one (Carpentras).

Use of a seasonal model. Examination of the correlation coefficients of the variable and some of its increments led us to use at first [1]

$$w_i = \nabla\nabla_{365} I_i = (I_i - I_{i-365}) - (I_{i-1} - I_{i-366})$$

and the model

$$w_i = (1-\lambda B)\ (1-\mu B^{365})\ a_i$$

$$= a_i - \lambda a_{i-1} - \mu a_{i-365} + \lambda\mu a_{i-366}$$

where a_i is a white gaussian noise. The optimal values of the coefficients λ and μ were found nearly independant of the site. The quality of previsions obtained with this model is, besides, not much affect by variations of $\pm$ 0,1 of these coefficients. The values $\lambda = 0{,}9$ and $\mu = 0{,}7$ give good simulations on a few months periods, and with some modifications on arbitrary long periods, except for the mediterranean site. The first modification consisted in a preliminary exponential transformation of the insolation in order to obtain an unsymetrical process with respect to the local mean, as in the real process. Such a transformation was not sufficient in the case of the mediterranean site, of which I shall speak later.

Use of a short term model. The model previously presented can be used only if more than one year of measurements is available and, to get rid of this drawback, we examined simple models [2] operating on

$$v_i = I_i - I_{i-1}$$

At first we tried to obtain local models, with different parameters for the different seasons. However the best results were obtained with mean values of the parameters and among the different models tested, the following one gave the best results :

$$v_i = a_i - \theta\ a_{i-1}$$

With about 15 days'observation this model yields one-day-previsions which are better than those given by the seasonal model, and generally better than those given by estimators of the daily mean.

Third Model. We have observed that the correlations obtained for the increments w_i or v_i are well explained with the variable

$$z_i = I_i - < I_i >$$

and the simple following MA(1) model :

$$z_i = a_i + P\, a_{i-1}$$

This model is more convenient to get simulations of the studied process than the former ones as it gives processes without any drift. With a preliminary exponential transformation and cutting off some peaks out of reasonnable limits, this model gave with a standard white noise good simulations for our temperate site and our equatorial site.

Case of the mediterranneen site. The high probability of clear days in mediterranean sites gives a particularly disymetric distribution of daily irradiation, and the above methods did not give good simulations. We used then a stronger preliminary transformation which consisted in obtaining an auxiliary process approximatively centred on the mean of the irradiation obtained on good weather days, by an adjusted multiplication of the values exceeding this mean. This auxiliary process is simulated as previously and the inverse transformation is performed on it to obtain the simulated irradiation.

We can observe that as well for simulation as for prediction, the first model which is of the standard form of models used for seasonal series is in fact not the better.

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DOMESTIC UTILIZATION OF SOLAR ENERGY IN THE MICHIGAN AREA

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EXTENDED ABSTRACT

INTRODUCTION

At present hot water and space heating in residential buildings account for about 14% of the total energy usage in the United Sattes. As the cost of conventional energy sources escalate solar energy appears to be attractive for domestic utilization. There is some confusion on the effectiveness of solar energy for space and water heating. A study was thus conducted to evaluate the effectiveness and potential of such a system in Michigan area.

ANALYSIS

A typical family house lying around 43° North and 83° West latitude was considered in the analysis. A computer model was designed to determine the heating loads during the fall and winter season. The heating requirements were based on the local climatological data published by NOAA [1]. A flat plate collector system was incorporated to determine the effeciency of solar energy conversion to thermal energy. Local solar insolation based on the published data [2] was used in the calculations. Various temperatures of the working fluid were analysed to determine the effectiveness of the system.

RESULTS

To make the system potentially attractive from energy conversion considerations the fluid temperature need to be kept low particularly during colder winter months. This restricts the use of solar collector as the primary energy source since the temperature of the working fluid was inadaquate for heat transfer. It was found that solar energy system would be attractive in conjunction with a heat pump.

The cost benefit analysis shows that the potential of such a system is determined by :

a. The life expentancy of the collectors and the associated equipment.

b. The cost of natural gas and heating oil over the years.

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USE OF SOLAR ENERGY IN MULTI-STORY BUILDINGS

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TENDED ABSTRACT

INTRODUCTION

Use of solar energy is unfortunately still in the stage of experimentation. A very efficient means of ending the energy crisis would be the economical production of a synthetic fuel that could replace the use of fuel as an energy source. A synthetic renewal of the process that stored solar energy in fossil fuels, thousands of years ago will solve the fuel problem but provision of comfort conditions in buildings has to be treated separately from the fuel crisis. Solar energy can be efficiently used to achieve this goal.

BIOCLIMATIC COMFORT

The comfort range of environmental factors for human beings depends on their activity level and clothing. The air temperature, mean radiant temperature, air motion and humidity all effect human comfrot. Comfort boundaries range from 18°C to 25°C at most. Whereas human beings consume roughly one-third of their total energy consumption (30% in Turkey) to achieve a bioclimatically comfortable environment. By doing so they are depleting all the nonrenewable sources of energy as well as valuable resources of industry and agriculture such as wood, fuel oil, coal and animal excretion.

Actually, human comfort can be achieved with much less of an input as seen in the old days or in vernacular architecture where there are no sophisticated heating or cooling systems to provide comfort. Throughout centuries man have learnt to build their buildings in conformity with climate but tended to forget it with the use of sophisticated heating and cooling systems. Today, man has to learn once again means and methods to design climate balanced or energy efficient buildings, which make maximum use of solar energy in winter while protecting themselves, from it in summer.

Due to the high concentration of people in the urban areas, urban lots be-
e valuable and highrise buildings are built. A great percentage of
ldings are in the form of high rise buildings.

HIGH RISE BUILDINGS AND THEIR RECEIVING SURFACES

Use of solar energy in high rise buildings are more problematic compared to the use of solar energy in single detached houses or one or two story houses in the suburban neighborhoods. Due to the high cost of land the building lots are small compared to the usable area of the building. Therefore, the high rise building has a small surface area compared to the floor area, thus the receiving surfaces are limited.

Roofs

The roof is a building component which is most subject to the effects of climate. Therefore, it is most affected by solar radiation. Be careful design of the roofs they can be a very efficient tool to provide bioclimatic comfort all year-round and to collect solar energy in winter. This can be provided by a.) the determination of the slope of the roof and b.) treatment of the receiving surfaces. Having inclined roof surfaces has the advantage of receiving sun's rays perpendicularly in winter, and increasing the receiving areas.

Shutters

Shutters are very important tools for the bioclimatic planning of buildings. Whether a building is heated or cooled actively or passively by solar energy, shutters can be of great importance. Shutters can be designed as to act as solar collectors. But this multi-purpose use of collectors will need sturdy elements. The design and performance specifications for collector - shutters must take into consideration that they have to function at various inclinations, must be lightweight and durable against breakage.

Balconies

The floors and parapet walls of the balconies constitute a large percentage of the outdoor surfaces of high rise buildings. Floors can be used as collector surfaces but than a new concept of collectors must be considered in which collectors can be designed and made as tiles that would be strong enough to carry the furniture and human beings while being used. The concept of collector tile needs to be worked on for a long time yet, but it will be a very good solution to many problems in the future.

Walls - Windows

The exterior walls of a building is the largest collecting area present in a multi-story building. The walls can be used in a number of ways both in passive and active solar heating and cooling systems. In passive systems, they can be used as a tool to cause convection and radiation as in the case of a Trombe wall. They can also be used as receiving areas by placing collectors on them. Through the development of new building materials, or altering their existing characteristics of thermal storage walls will be used more effectively in the future.

The thermal properties of glass have resulted in the use of windows in bioclimatic design. By bringing a new concept that would unite walls and windows there will be a flexibility of solar design and a more effective means of solar control.

CONCLUSION

The outdoor climatic conditions are variable and unalterable by men. The goal of design is to achieve bioclimatic comfort conditions indoors whatever the outdoor climatic conditions are. The comfort conditions are only dependent on the activity level and clothing of the users. Up to now the energy input to achieve this bioclimatically comfortable indoor climate was considered almost limitless and independent of the characteristics of the building shell. Now after the energy crisis the aim is to build the building shell so that it would consume a minimal amount of energy to achieve comfort. In this new epoch multi-story buildings should be designed to achieve this goal.

IMPLICATIONS OF FEDERAL POLICY TO COMMERCIALIZE SOLAR TECHNOLOGIES

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In his June 20, 1979 speech President Carter established a policy th solar technologies will supply 20 percent of this nation's energy requirements by the year 2000. Contributions from individual technologies to reach this goal were established by the Domestic Policy Review Committee on Solar Energy (DPR). The majority of the 20 percent goal is projected to be supplied by technologies indicated in Table I.

TABLE I

DOMESTIC POLICY REVIEW SOLAR PROJECTIONS

Technology	Year 2000 Contribution (Quads)
Residential/commercial heating, hot water and cooling - active	2.0
Passive solar	1.0
Process heat	2.6
Hydroelectric	4.6
Biomass	5.4
Wind	1.7
Photovoltaics	1.0

Achieving these levels of solar market penetration requires a significant level of federal commitment to the commercialization of solar technologies. Current federal activities in support of solar commercialization are coordinated under the National Plan to Accelerate the Commercialization of Solar Energy (NPAC). Within NPAC the Regional Solar Energy Centers (RSECs) have been charged with developing regionally specific commercialization plans. This paper summarizes the development of the RSEC commercialization plans. Four levels of federal incentives, varying from the incentives provided under the NEA to a level of $1.90 per MMBtu of primary energy displaced, are analyzed to determine the regional market penetration of solar technologies. The regional market penetrations provide one indication of which solar technologies should be emphasized in the RSEC solar commercialization plans. Additional guidelines for RSEC planning purposes are also provided including:

- Descriptions of available, developmental and proposed solar technologies
- Solar resources
- Size and nature of the potential regional solar market
- Current status of the solar industry infrastructure
- Major implications of the regional development of solar energy.

Under a level of federal incentives sufficient to reach the 20 percent solar goal (approximately $1.60 per MMBtu of primary energy displaced), estimates of solar contributions in each RSEC region are show in Table II.

TABLE II

REGIONAL SOLAR ENERGY CONTRIBUTIONS

Region	Solar Contributors		Major Contributors
	% of Regional Demand	Quads Primary Energy Displaced	
Northeast Solar Energy Center	13	2.8	Wind, solar heating and cooling
Southern Solar Energy Center	12-17	5.4-8.0	Process heat, wind, solar thermal, solar heating and cooling
Mid-America Solar Energy Complex	12-16	3.9-4.8	Process heat, wind, solar heating and cooling, biomass conversion
Western SUN	31-35	5.0-5.5	Hydroelectric, process heat, solar heating and cooling

The analysis of costs and benefits of solar technologies was carried out using the MITRE System for Projecting the Utilization of Renewable Resources (SPURR) analysis. The analysis includes for each region:

- An extensive data base of solar technology costs, performance availability dates and learning curve cost reduction [1,2,3]
- Competing conventional technology cost/performance data [4]
- Scenario assumptions [5] - energy consumption, fuel costs, financial assumptions

- Incentives in support of solar technologies
- Market penetration methodology [6]

The primary results of the SPURR analysis include projections of solar energy market penetration and costs. Additional findings of the analyses indicate that to meet the presidential goal:

- Solar energy systems will be ubiquitous
- Extensive federal and RSEC programs are required to remove economic, institutional and legal barriers
- Levels of critical pollutants (SO_x, NO_x, CO_2) are expected to be reduced
- Federal RD&D programs must provide commercially competitive solar technologies as early as possible
- A vigorous and large domestic solar industry would be established.

The provision of this information on a regional basis enables the RSECs to characterize their solar markets and to identify applications with significant near term market potential. This information is used by the RSECs to identify leverage points, people or organizations who are expected to have a significant impact on solar market penetration for the region. This enables the regions to design commercialization programs to specifically address these leverage points. The commercialization programs developed by the regions include programs addressing the leverage points which:

- Provide education and information on solar technologies, programs and activities
- Support technology development
- Assist in industrial interface development
- Reduce legal and institutional barriers, and
- Accelerate market development.

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CGM

ENERGY POLICY IN A CHANGING SOCIAL ORDER

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EXTENDED ABSTRACT

United States energy policy has been shaped historically by the social context in which policy alternatives evolve. Throughout the transitions from wood to coal to petroleum and natural gas, national policy generally pursued the optimization of end-use convenience among energy users at the lowest private cost. An expanding economy, together with government subsidies, supported this policy in an unobtrusive yet deliberate fashion. While explicit national energy programs did not characterize this era, an energy policy was advanced nonetheless via surrogate government mechanisms which included housing, transportation, commerce and tax policies. Within this social context, national perception failed to openly acknowledge the prospects for eventual decline in fossil energy supply. Moreover, the sustained ability and self-interest of the private sector in delivering low cost energy proved crucial to the broader and more salient political objective of raising the relative standard of living across all social classes.

Quite abruptly, political, economic and ecological realities have combined to alter the social environment in which U.S. energy policy options must develop. Such change has come at a time when percapita consumption of energy has reached record levels. This consumption pattern, together with a changing international power balance, strengthened environmental sensibilities and increasing marginal production costs of fossil fuels has helped expose the non-renewable nature of our current energy resource base. In turn, the world political marketplace has quickly imposed a new price structure on our energy consumption habits. Energy policy options must now be adjusted to the emerging and not totally understood social context which characterizes United States' energy resource utilization.

At first glance, development of a new national energy policy is constrained by an economic environment where political choices are increasingly narrow and unpopular. Irreconcilable trade-offs between conventional energy investment (inflation) and sudden demand reduction (recession) are suggested by most conventional policy options. Government decontrol of petroleum and natural gas prices appears to be only the first of many painful policy steps which the nation faces in its attempt to manage demand and encourage supply of non-renewable energy sources.

Importantly, the decontrol of domestic petroleum and natural gas prices, together with continued rises in the OPEC price structure, reflects the surging marginal production costs for these fuels. Extraction costs for increasingly inaccessible energy resources along with rising environmental control costs are combining to drive delivered energy prices beyond any proximity to past charges. This is occurring even without consideration of the added costs which would arise from elimination of the pervasive subsidization of these fuels which now exists. At the same time, national concern over strategic vulnerability has intensified, bringing renewed emphasis and political support to the perceived security of a domestic synthetic fuels industry. The continued disparity between the expected costs of liquid synfuels and the world market price for petroleum is apparently not significant enough to deter synfuels policy advocates. Clearly, factors other than the delivered price of energy are beginning to define the energy policy objectives now being debated at all levels of government.

The lack of substitutability among conventional fuels and varying costs of production will continue to result in some price differentials, both for primary fuels and delivered energy. Nevertheless, as evidenced by pricing trends before and after the 1973 embargo, price convergence on a BTU basis among fossil fuels has increased. Should this trend intensify, our once immediate energy policy goal of lowest-cost supply may effectively yield to overriding considerations of long-term price and resource stability. With fewer low-cost conventional energy alternatives available, energy planners may more easily focus on a broader range of policy options of equal or greater value to the overall security and long term interests of the nation.

Within this evolving policy framework, ecological stability, revitalized international trade and monetary positions, strategically less-vulnerable energy distribution systems and more equitable public access to energy supply all become eligible to supplant "end use convenience at the lowest private cost" as the principal driving force behind national energy policy. A variety of conservation, solar and other renewable energy options conveniently respond to each of these potential policy determinants. Cost and end-use prices will certainly remain significant factors in energy planning. However, the amplification of longer term social values within the policy process represents a fundamental restructuring of the national energy decision making framework.

At a more advanced stage of development, energy policy could easily come to control the once dominant political forces represented in housing, transportation, labor and commerce sectors. To the extent that a changing social context forces consideration of more than raw economic criteria in energy policy making, an increasingly favorable environment will be created for the advocacy of solar and other renewable energy options. It is an opportunity which should not go untested.

D.A.S.

HIGH TEMPERATURE SOLAR POWER TOWER PLANTS CONCEPT CONSIDERATIONS AND OPERATIONAL CRITERIA

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EXTENDED ABSTRACT

If solar energy contributes one day or another to a considerable extent to Europe's energy supply, it will necessarily be by way of some noble form of energy like electricity and chemical products. The reason for this is that the scant European solar radiation does not allow reasonable large scale energy conversion in loco so that the energy has to be transported from sunny regions of the world to the consumer's place. Helioelectric power plants are in that context important solar energy conversion machines for both, inner, as well as, extra-European conversion sites. From the Southern European countries or from well insolated Alpine regions electricity may directly be fed into existing grids. The transportation from far away equatorial regions to Europe has to be done by energy rich vectors like chemicals, where hydrogen is a prime candidate for well known reasons. Here also the helioelectric power plant is the prime component in the solar energy - hydrogen chain since electrolysis will probably turn out to be the most convenient way of hydrogen production.

A problem of solar electricity generation is its more or less decentralized mode of rather small scale unit rating; helioelectric power plant ratings will hardly exceed 100 MW(el). The management problems of this type of pwoer generation with its implications of grid interference specifically pertain to solar electricity generation but are of similar nature for total energy converters, i.e. heat/power coupling within internal combustion engines.

In the framework of its solar energy research and development program, the Commission of the European Communities decided in 1975, to build a helioelectric demonstration plant of rather large rating. In order to take advantage of the high exergetic potential of the solar energy, it was decided to use high temperature of the working fluid by means of high concentration in the power-tower concept.

The size of 1 MW was the result of the reasoning that for useful spending of the money the smallest size of an apparatus should be built which by its intrinsic concept allows extrapolation of the technology into higher and highest ratings. At that time, first evaluation studies indicated the cross-over point of investment cost and energy price between distributed system and towers at about 500-700 kW. To be sure of our choice and in

order to have a representative rating, the 1 MW(el) seemed to be a sound size.

An European Industrial Consortium has been setup for the layout and construction of the plant, consisting of:

- ANSALDO SpA and Ente Nazionale per l'Energia elettrica (ENEL), Italy
- CETHEL (combining Renault, Five-Dail-Babcok, Saint-Gobain Pont-a-Mousson and Heurtey S.A.), France
- Messerschmitt-Bolkow-Blohm (M.B.B.), Germany

The site of the power plant is at Adrano, a village 40 Km west of Catania, Sicily. It has an average elevation of 220 m, a north-south inclination of 5% and lies near a small river. The operational requriements of this Experimental Solar Power Plant are not only to study the performance of certain components like heliostats and receiver, but it shall already produce electricity and feed it into the existing grid of the Italian National Electricity Generating Board, the ENEL. By this virtue, it will be possible to study electric power generation and problems of grid interface.

The operational requirements described in the paper are valid in general for solar power plants; they pertain, however, specifically to the EURELIOS power plant. The steam cycle of solar plants has to operate under special conditions, asking for:

- turbine by-pass, allowing direct steam flow from receiver to the condenser
- energy bufrer, for smoothening operation at clouds passage
- emergency system, allowing functioning of pumps and other vital accessories in case of sun disappearance, system or grid failure
- maximum power generation at any moment, including large insolation variations
- guarantee the life of the receiver in transient conditions.

Some economic and material requirement considerations are made indicating the fact, however, that published figures vary still considerably.

The authors invite not to have illusions on the share solar power plants will have on our electricity production; it will not be until the middle or end of the next century that solar power plants will have, say, a 50% share of it, if ever.

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SESSION 6C

INDUSTRIAL SOLAR APPLICATIONS

ABSTRACT

DYNAMIC RESPONSE ANALYSIS OF A SOLAR POWERED HELIOTROPIC FLUID-MECHANICAL DRIVE SYSTEM

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The need for a tracking mechanism developed while researching methods of providing a 24-hour cooking capability with solar energy. Decisions were made to utilize a liquid heat transfer medium (cottonseed oil) and a sensible thermal storage system in association with a large parabolic concentrating collector to implement this cooking capability. In order to maximize the solar collection by this collector, a tracking device was necessary to drive it from an east facing to a west facing orientation. Furthermore, it was decided to consider a feed-back control instead of a clock motor.

The results of this research produced not only a drive mechanism with feed-back control but also one which required no external utilities source for its power. The unit, as presently designed, utilizes a low boiling point fluid and two power cylinders connected to a drive mechanism for the collector. Pressure differences in the sensors due to fluctuations in collector alignment provide the driving potential to maintain the collector in proper aspect to the sun.

This paper will provide design data and operational data for this solar powered tracking device. Illustrations of its use and a discussion of its utilization for other solar energy projects will also be presented.

ABSTRACT

A Solar-Energy System for Automotive Transportation

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Increasing cost and scarcity of petroleum signals its passing as the primary energy-source for automotive vehicles. Liquid hydrocarbons derived from nonpetroleum sources are being investigated as replacements, but the economic and environmental costs of extracting suitable liquid hydrocarbons from shale-oil, coal, biomass, etc. appears to be formidable, if not prohibitive. Both hydrogen-fueled vehicles and electric vehicles have been considered as future substitutes for petroleum-fueled vehicles, but since electricity and hydrogen are "energy-carriers" they require a primary energy source. The future of nuclear power is clouded by economic and environmental problems. Solar energy could be used as the primary energy source, however.

But previous analyses by the senior author have shown that the direct utilization of solar-thermal energy for automotive transportation is economically more attractive than the indirect hydrogen generation or electrical generation paths.

The proposed paper presents a preliminary design of a solar-energy system for automotive transportation The vehicle envisioned

is composed of a Stirling engine that converts to mechanical work at the wheels thermal energy stored on board in "thermal-batteries" inorganic salts with high heat capacity. Heat is transferred from the batteries to the engine. The solar energy is collected and stored at stations at which the vehicle can be charged.

Both the vehicle and station are considered in the preliminary design. The station configuration was limited to components that are being developed for solar/electric power generation, and ar scheduled for mass production within a decade. The Stirling engine being developed for petroleum-fueled vehicle application within a decade.

Specific design issues considered include the optimization of station size and selection of salts for minimum life-cycle.

Example calculations will be presented to illustrate the desig methodology.

A SOLAR INSTALLATION FOR PROCESS STEAM GENERATION FOR A REFINERY

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EXTENDED ABSTRACT

In 1980 a solar steam generation system to provide steam for the Southern Union Refining Company in Hobbs, New Mexico, will become operational. A schematic diagram of the solar system is shown in Figure 1.

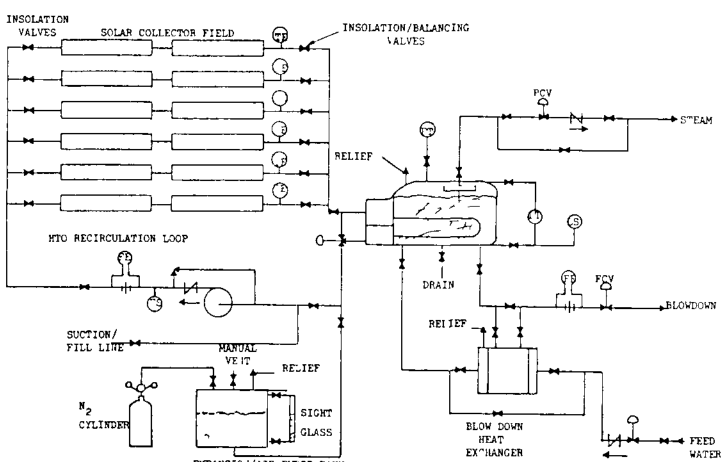

Figure 1. Schematic of a Solar System for Oil Stripping Process

The solar steam generation system consists of collectors, heat transfer fluid and pump, heat transfer fluid expansion tank, steam generator, blowdown heat exchanger, and several control valves. Saturated steam at

190°C/12 kg/cm^2 (375°F/175 psig) is generated by 136 m^2 (10,080 ft^2) of parabolic trough collectors having about a 16X concentration ratio. The collectors form 12 arrays with 6 collectors in each array and they will be mounted on the ground. The arrays are East-West oriented and they interface with the refinery system through a steam generator. Each collector array has a separate tracking/drive unit. The location of the collector arrays and an overview of the refinery is shown in Figure 2.

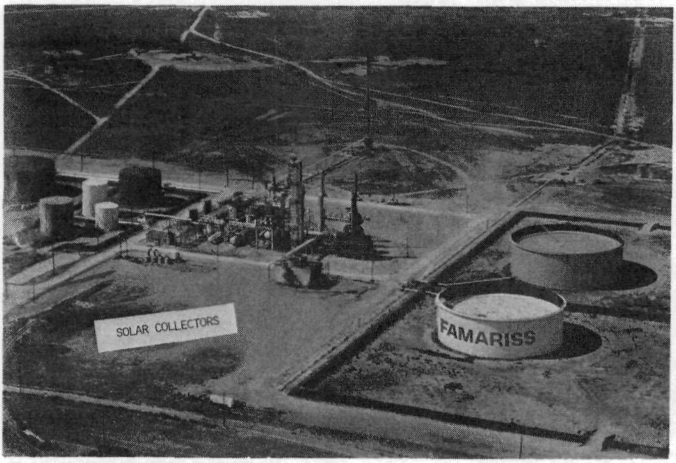

Figure 2. An Overview of the Famariss Refinery in New Mexico, U.S.A.

The solar system is a two loop system (see Figure 1); a heat transfer oil circulates in the collectors loop while steam is generated in the steam generator loop. Solar radiation absorbed by the collectors is converted into the heat of the heat transfer fluid (Therminol T-55 of Texaco) and then is transferred through the heat exchanger and the second loop to the steam generator. The steam generator transfers the heat from the heat transfer fluid to the incoming feedwater, thereby producing steam. The cool incoming feedwater is preheated by the blowdown heat exchanger thus making it possible to recover some of the wasted energy in the liquid blowdown. Although the blowdown system wastes a fraction of the collected solar energy, it is necessary in order to control corrosion and scaling in the solar system. The heat transfer fluid expansion tank provides the required volume for expansion as the recirculating fluid increases the temperature during system start-up. A controlled inert atmosphere is maintained in the expansion tank to prevent explosions and to reduce corrosion and chemical breakdown of the T-55 heat transfer fluid. A constant flow rate of the heat transfer fluid is maintained in the recirculation loop and only the fluid temperature in the collector field varies in response to variations in solar flux. This type of system operation allows the recirculation fluid temperature at the exit of the collector field to be in the range of 260°C (500°F) to 190°C (375°) throughout the day. The collectors daily thermal output is then 16.46 x 10^6 Joules per square meter (1450 Btu/ft^2) with a corresponding day long efficiency of 48%. The peak collectors thermal output is approximately 2 x 10^9 Joules/hr (1.97 x 10^6 Btu/hr) with a resulting 658 kg/hr (1,882 lb/hr) steam flow. On an annual basis the solar system will provide a thermal process heat equivalent to 9.34 x 10^4 m^3 (4.64 x 10^6 ft^3) of natural gas.

It has been estimated that at least 137 refineries throughout the U.S. could be equipped with similar solar systems.

The paper will also briefly discuss the basic economic aspects of solar industrial process heat applications on the base of the general trend of current cost variation of solar thermal systems in function of system size as is shown on Figure 3.

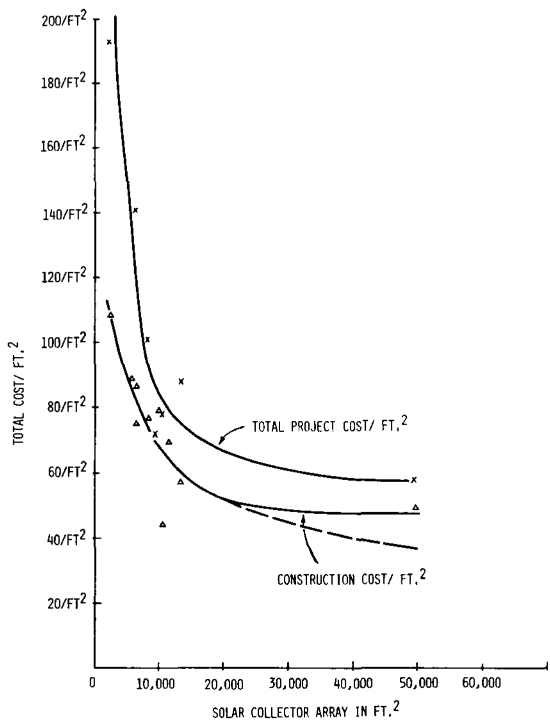

Figure 3. General Trend of Current Cost Variation of Solar Thermal Systems with System Size.

NEW SOLAR STILL REALIZATION AND EXPERIMENTATION

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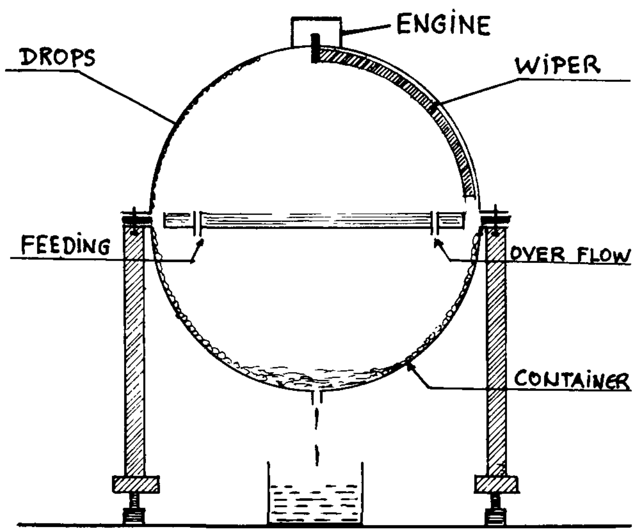
EXTENDED ABSTRACT

CLASSICAL SOLAR STILL

The classical solar still (plan) is of a great thermic inertia, meaning weak efficiency (max 30 - 35 %) and high rigidity. Due to its geometric form, the transmitted solar radiation inside the still is limited ; at the same time, the condensed drops on the surface exposed to the sun, slowly drained by gravity, will also reduce the percentage of transmitted radiation.

NEW APPARATUS : SPHERICAL STILL

Conception



G.M.

For equal horizontal area of the basin, the spherical form of the transparent surface will allow a better exposure to the sun and will offer a greater area for condensation.
The wiping of this surface will keep it constantly transparent for solar radiation.

Performances : The experimentation of this new still has clearly given much better results compared to the classical still : the distilled water production by square meter of the horizontal area of the basin and the efficiency were improved about 30 % ; the termic inertia was reduced approximately four times. This new aparatus is not heavy, and its cost price in series is reduced, which will certainly reduce the price of the distilled water.

Applications of this new still : Very wide :

- Production of distilled water for different utilities (laboratories, industrial, pharmaceutical, etc...)
- Production of drinking water in isolated areas (simple apparatus easy to transport) after being treated with added salts and minerals.
- Treatment of polluted water.
- Drying of garbage before incineration

A patent was obtained for this apparatus. Different contacts have proved the existence of great demand for such a system, and mass production will start soon.

SOLAR ENERGY IN THE FIELD OF DISTILLATION-DESIGN PARAMETERS AND THERMODYNAMIC ANALYSIS OF SOLAR STILLS-A NUMERICAL STUDY

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EXTENDED ABSTRACT

INTRODUCTION

This paper outlays some of the design parameters involved in both natrural convection and forced convection solar stills.

BASIC DIFFERENTIAL EQUATIONS

The laminar boundary layer equations[1] for evaporation of water in a hot-box type solar system as follows:

Momentum equation

$$\frac{d}{dx}\int_0^{\delta} u^2 dy = -\nu\left(\frac{\partial u}{\partial y}\right)_w + \left[g\beta_m \int_0^{\delta_1}(c - c_\infty)\,dy + g\beta_t \int_0^{\delta_2}(T - T_\infty)\,dy\right]\sin\alpha \quad (1)$$

Diffusion equation (2)

$$\frac{d}{dx}\int_0^{\delta_1} u\tilde{c}\,dy = v_w - D\left(\frac{\partial \tilde{c}}{\partial y}\right)_w$$

Energy equation (3)

$$\frac{d}{dx}\int_0^{\delta_2} u\theta\,dy = v_w - a\left(\frac{\partial \theta}{\partial y}\right)_w$$

where $0 < \alpha \leq 90^\circ$ and $v_w = \frac{-D}{1 - c_w}\left(\frac{\partial c}{\partial y}\right)_w$

since density is a linear function of concentration and temperature

$$\beta_m (c - c_\infty) + \beta_t (T - T_\infty) = \frac{\rho - \rho_\infty}{\rho}$$

These set of equations are solved by assuming suitable velocity concentration and temperature profiles.
A modified method to solve the above equations is suggested here which takes into account the Soret effect(thermal diffusion) and the Dufour effect (energy transport by convection) which are hitherto neglected in the above equations. The method, given below, takes into account the variation of properties and also the inertial effects. The above three equations can be transformed into a generalised equation as

$$\frac{\partial \phi}{\partial x} + (a + b\omega) \frac{\partial \phi}{\partial \omega} = \frac{\partial}{\partial \omega} \left(c \frac{\partial \phi}{\partial \omega} \right) + d$$

where may represent velocity, concentration or temperature.

$$a = \frac{-1}{(\psi_E - \psi_I)}$$

$$b = \frac{-1}{(\psi_E - \psi_I)} \quad \frac{d}{dx} (\psi_E - \psi_I)$$

$$c = \frac{r^2 \rho u \Gamma_{eff}}{(\psi_E - \psi_I)^2}$$

$$d = \frac{1}{\rho u} S_\phi$$

$$\omega = \frac{\psi - \psi_I}{\psi_E - \psi_I}$$

Here Γ_{eff} represents the effective transport property and denote the momentum or enthalpy source terms. Suffices I and E denote internal and External surfaces.

SOLUTION PROCEDURE

Implicit forms of finite difference equations are solved by tridiagonal matrix algorithm after forming them from the differential ones by integration over control volume.

The above three equations can be solved by the above technique for the velocity, temperature and concentration profiles.

OTHER PARAMETERS

The paper further analyses the (i) Radiation characteristics and the losses by reflection from a still (ii) Heat and mass transfer characteristics of both natural and forced convection solar still.

CONCLUSION

Thus the analytical paper elaborately describes the various design and thermodynamic paramters involved in a solar still.

GK

NOMENCLATURE

u, T, c - Velocity, Temperature and Concentration of the salt water

$\delta, \delta_1, \delta_2$ - Thicknesses of velocity, temperature and concentration profiles

$\theta = \frac{T-T_\infty}{T_w-T_\infty}$; $\tilde{c} = \frac{c-c_\infty}{c_w-c_\infty}$, Non-dimensional values

α - Inclination of the surface

a, ρ - Thermal diffusivity, density

D - Diffusion coefficient

Suffices ∞, w denote the free stream and wall conditions.

REFERENCES:

1. Khamadov, A., 'Heat and Mass Transfer during evaporation under natural convection'- Applied Solar Energy, Vol.10. No.1, PP 41-44, 1976.

2. Spalding, D.B., ' GENMIX: A general Computer program for two-dimensional parabolic phenomena' - Pergamon Press, New York, 1977.

HEAT GENERATION FOR MULTIPURPOSE UTILIZATION SYSTEMS BY HEAT OF DILUTION CONVERTED FROM SOLAR ENRGY

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EXTENDED ABSTRACT

INTRODUCTION

Solar energy utilization systems are ordinary thought to be one for carrying out only one function such as solar heating, cooling and hat water supply systems or solar thermal power generation systems. However, heat energy collected at the high temperature is useful for multipurpose utilization systems, for example, solar heat and electricity supply system. On the other hand, it was shown in our paper [1] that heat of dilution converted from solar energy is suitable for high temperature heat generation and solar energy storage. So, application of heat of dilution to multipurpose utilization system was analyzed in this paper and the effectiveness of heat recovered from heat of dilution was considered by numerical calculations.

PERFORMANCE ANALYSIS IN MULTISTAGE MIXING COLUMN

Although the selection of the solution which generates heat of dilution is very important, sulfuric acid and water solution is used in this analysis because its thermodynamic properties are well known. Figure 1 is the schematic model of multistage mixing column for generating heat such as industrial process heat and domestic heat and steam for a turbine generator. In this system, the heat produced in an arbitrary mixing vessel is consumed in order to heat the solution mixed there,i.e. Gwj and Gaj, and the sulfuric acid and water being mixed in the next mixing vessel,i.e. Gwj+1 and Gaj+1. Gwl+2 and Gaj+2 indicated in Fig.1 flow into a preheating vessel and are heated there by the solution flowing out of a mixing vessel. The solution flowing out of a preheating vessel is carried into a heat exchanger installed outside the column, and industrial process heat and domestic heat is produced by heat exchange at the heat exchanger. A boiler is installed at the final mixing vessel, at which steam is produced for running power generator. The enthalpy balances in column are as follows:
at the preheating vessel,

$$G_{aj+1}(i'_{aj+1} - i_{aj+1}) + G_{wj+1}(i'_{wj+1} - i_{wj+1}) + (G_{aj-1} + G_{wj-1})(i'_{j-1} - i_{j-1}) = 0 \quad (1)$$

at the mixing vessel,

$$G_{aj+1}(i''_{aj+1} - i'_{aj+1}) + G_{wj+1}(i''_{wj+1} - i'_{wj+1}) + \Delta Q = 0 \quad (2)$$

where

$$\Delta Q = (G_{aj} + G_{wj})i_j - (G_{aj}.i_{aj} + G_{wj}.i_{wj})$$

and at the final mixing vessel,

$$(G_{af} + G_{wf})i'_f - (G_{af}.i_{af} + G_{wf}.i_{wf}) + m\Delta i = 0 \quad (3)$$

i_a,i_w and i_j express the enthalpies at T_j and are functions of temperature. i_a and i_j are the enthalpies of 90wt % H_2SO_4 and 70 wt % H_2SO_4, respectively. i' and i'' indicate the enthalpies at the outlet of the preheating vessel and of the mixing vessel, and are the enthalpies at t_{j+1} and T_{j+2}. And G_a and G_w are the weight flow rate per arbitrary unit time of sulfuric acid and water. ΔQ is the enthalpy change of the solution mixed there. And m is the weight flow rate of saturated steam and corresponds to the water flow rate flowing into the boiler. Δi is the enthalpy difference between saturated steam at T_s and saturated liquid flowing into the boiler. This analysis was made by assuming that the temperature of the solution is prescribed at each mixing vessel and that the weight flow rate of the sulfuric acid and water are controlled until its prescribed temperature is reached. As for condition of concentration, initial concentration is 90 wt % and concentration after mixing is 70 wt %. The details of the assumptions made in analysis, the optimum condition of the dilution and the procedure of numerical calculations are described in Ref. 1. And initial conditions of the temperature and the flow rate are as follows:

$$T_1 = T = 20\ °C, \quad G_{a1} = 1400\ Kg/time.$$

RESULTS

Figure 2 is one typical example of the results obtained by calculations and indicates the effect of $\bar{T}_1$ on weight flow rate at various temperature obtained from the heat exchanger under the condition of $\bar{T}_2$ = 110 °C, $\bar{T}_3$ = 160 °C and T_s = 240 °C or 260 °C. Figure 3 indicates the flow characteristics under the same conditions of Fig.2. It is shown from Fig.2 and Fig.3 that surfuric acid flow rates in each stage and water flow rate obtained from heat exchanger are affected by prescribed temperature in each stage. Figure 4 indicates the ratio of water flow rate obtained from heat exchanger to total sulfuric

acid flow rate in multistage mixing column. As shown from this figure, a large amount of thermal energy can be generated by heat of dilution and can be recovered by heat exchanger.
The detailed discussions of various results made by numerical calculations would be described in complete manuscript.

REFERENCE

[1] T.Tanaka et al., Energy Conversion, Vol 18,57-65, (1978)

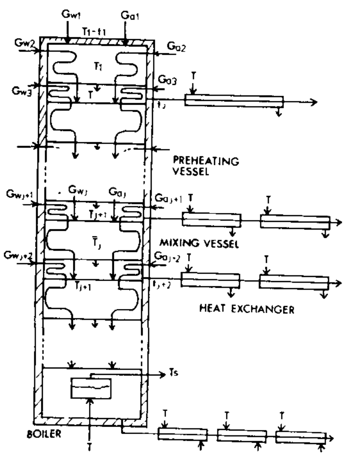

Fig.1 Schematic Model of Multistage Mixing Column

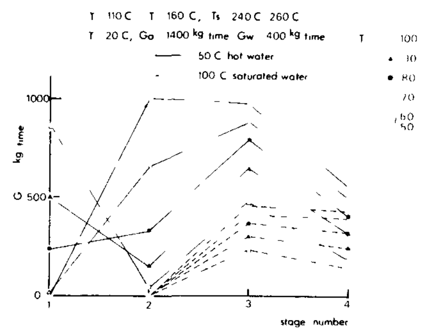

Fig.2 Water Flow Rate at Various Temperature obtained from Heat Exchanger

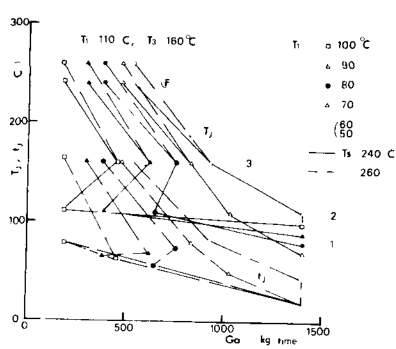

Fig. Flow Characteristics under the Same Conditions of Fig.2

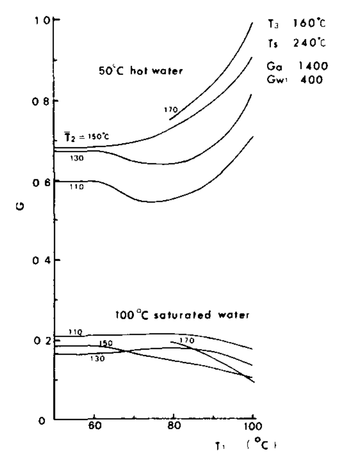

Fig.4 Ratio of Total Water Flow obtained from Heat Exchanger to Total Surfuric Acid Flow Rate

TT

THEORETICAL ANALYSIS AND EXPERIMENTAL PERFORMANCE OF A FLUIDYNE PUMP

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EXTENDED ABSTRACT

INTRODUCTION

A number of attempts have been made in different countries to use the solar energy for pumping water. These attempts have used different principles and have been successful to varying degrees. Some solar pumps based on low temperature heat engines have been built and tested. These attempts seem to hold out a promise of their practical use in the near future. Operating temperatures of such engines are generally below 200°C, which for heat engines can be considered a low temperature range.

One promising design is the fluidyne pump which works on the principle of the liquid piston engine. One laboratory model of this pump was built and tested at the Indian Institute of Technology, Kharagpur. The test results are presented. A design theory for the pump has also been formulated.

WORKING PRINCIPLE AND DESIGN

The pump works on the principle of the liquid piston engine which operates on a sterling cycle. The output is in the form of pulsating pressure which can be used to operate one way valves for pumping.

A schematic of the pump is shown in Fig. 1. The water column in the U-tube oscillates at its natural frequency. As a result, the air above the water is displaced between the hot and cold regions. In the hot region, the air expands, pressure rises, and work is done by forcing water out of the output valve. In the cold region, the air contracts, pressure drops resulting in opening of the inlet valve through which water is drawn in. This process repeats itself at the natural frequency of oscillation of the water column.

As seen from Fig. 1, the pump consists mainly of a U-tube in which a water column of length L_w oscillates. The equation of motion for the water column is obtained from balancing of gravitational and inertial forces.

$$L_w x + 2\rho gx = 0 \qquad (1)$$

The equation gives the natural frequency as

$$w = \left(\frac{2g}{L_w}\right)^{y2} \quad (2)$$

Designing the pump for a discharge rate, Q, the output power, P, is given by

$$P = \rho\ g\ QH \quad (3)$$

The discharge per cycle is given by

$$V_0 = \frac{0}{w} \quad (4)$$

and $$v_i = v_0 \ \frac{P_{mean}}{P_a} \left(\frac{T_c}{T_h - T_c}\right) \quad (5)$$

where, $$P_{mean} = \frac{P_s + P_d}{2} \quad (6)$$

If the tube diameter is d, the length of air column for the initial volume v_i is obtained as

$$L_s = \frac{4v_i}{\pi d^2} \quad (7)$$

The total length of the tube would therefore be sum of water column length and the air column length,

$$L = L_w + L_a \quad (8)$$

The assumption of linear flow must be satisfied.

Hence,

$$Re = \frac{2\rho v_0\ w}{\eta \pi d} \quad (9)$$

This must be below the critical value of 2.000

The pressure developed by a fluidyne pump is limited by the working temperature. Assuming the engine works on a sterling cycle, the limiting value of the suction pressure P_s given by, $P_{mean} \nmid (T_h/T_c)P_s$, since P_{mean} =

$\left(P_d + P_s\right)/2$, this condition can be written as,

$$\frac{P_d}{P_s} \left(\frac{2\,T_h}{T_c} - 1\right) \qquad (10)$$

EXPERIMENTAL INVESTIGATION

A model was designed for a discharge rate of 500 ml/min with the hot region at 97°c (370 k) and the cold region at 27°c (300 k). The design values calculated as per procedure outlined above, were as follows:

w = rod/s

L_w = 50 cm.

v_i = 40.7 ml

L_a = 13 cm.

L = 63 cm., d = 2 cm.

A glass model with the above specifications was made. Glass jackets at hot-end and cold-end were provided. Steam obtained by electrical heating was used at the hot-end. The pumped water was passed through the cold-end jacket. Arrangement was made for varying suction and delivery head. It is found that increase in delivery head results in appreciable reduction in stroke length, which corresponds to a decrease in the volume of air being transferred back and forth between the hot and cold region. As a result, the change in volume is smaller. Hence, the discharge is less. It is observed that beyond a certain delivery head, there is a sharp reduction in stroke length.

The experimental results from the model indicate that the power output increases as the suction head is increased. In fact, the peak power output is found to be proportional to the suction head.

A maximum power output of 0.1 watt was obtained at the suction head of 1.2 m.

NOTATION

L_a	Total length of air column in U-tube (initially)
L_w	Length of water column = $L - L_s$
P	Power output
P	Pressure of working fluid (air)
P_a	Atmospheric pressure

P_d	Discharge pressure
P_s	Suction pressure
T_c	Temperature at cold-end
T_h	Temperature at hot-end
V_i	Initial volume of air
V_o	Discharge per cycle = 2 Δ v
ρ	Density of water
w	Natural circular frequency of oscillation of water column.

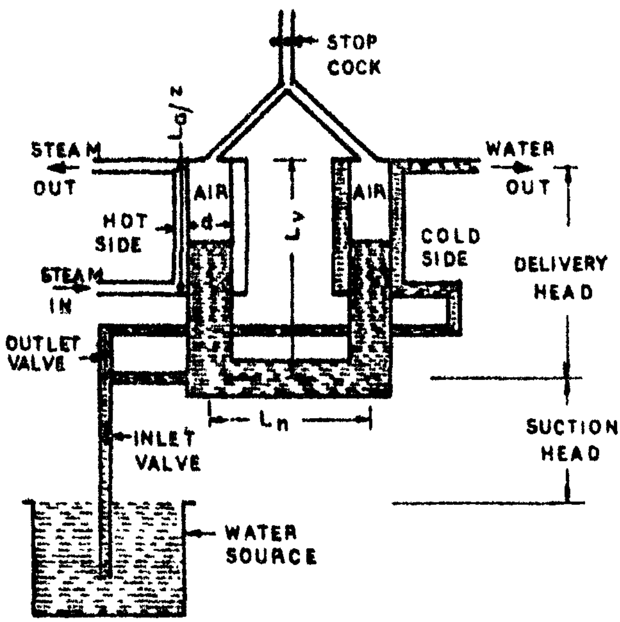

Fig. 1 Fluidyne Pump

SESSION 6D

WIND ENERGY II

ESTIMATING THE WIND'S POTENTIAL FOR SMALL SCALE ENERGY GENERATION USING AVAILABLE LOCAL CLIMATOLOGICAL DATA

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EXTENDED ABSTRACT

INTRODUCTION

Before investing large sums of money in expensive wind energy generation equipment, it is important to estimate the wind energy available at the tentative site. It is necessary however not to make an extreme under-estimation of the available wind energy by using yearly, monthly, or even daily wind velocity averages, except with modifying factors. This article will present a method of determining the wind's potential for small scale energy generation by using available data from a nearby N.O.A.A. weather station.

NOMENCLATURE

A sweep area of wind turbine blades (m^2)

E_k, $\dot{E}_k$ kinetic energy of the wind, total, instantaneous (W h), (W)

E_o, $\dot{E}_o$ energy output, total, instantaneous (W h), (W)

$\dot{m}$ mass flow rate of the wind (kg/s)

t, dt, Δt time, time interval (s) or (h)

V wind velocity (speed) (m/s) or (mi/h)

η wind turbine efficiency of conversion

ρ density of the atmosphere (air) (kg/m^3)

THEORY

The available kinetic energy of the wind per unit time is:

$$\dot{E}_k = 1/2\ \dot{m}\ V^2 = 1/2\ \rho\ A\ V^3 \qquad (1)$$

For any wind turbine, only a portion of this kinetic energy can be converted to usable power output ($\dot{E}_o$), the ratio being the efficiency (η), sometimes referred to as the power coefficient. This ratio has a maximum value of 0.593. [1]

$$\dot{E}_o = \eta \dot{E}_k = 1/2\ \eta\ \rho\ A\ V^3 \qquad (2)$$

This energy output is an instantaneous quantity. To find the total energy output (E_o) over a period of time, multiplication by a time interval is required. Density, efficiency, and area can be assumed constant, but the wind's velocity varies considerably with time, therefore the total energy output is:

$$E_o = 1/2\ \eta\ \rho\ A \int_o^t (V^3\ dt) \qquad (3)$$

Graphically, the integral part of the equation is equal to the area under the V^3 versus time curve. Wind turbines start producing energy output at a certain minimum velocity (usually about 3-4 m/s) and reach rated output at some rated wind velocity and higher (about 9-12 m/s). Therefore, by ignoring the area below a minimum V^3 value and the area above a maximum V^3 value, the net area, when multiplied by ($1/2\ \eta\ \rho\ A$) will give the estimated total energy output for a particular period of time.

ENERGY OUTPUT ANALYSIS

For small scale energy generation, when the lack of on-site wind velocity data exists, data obtained from N.O.A.A. [2] for a nearby national weather station of wind velocities at three hour intervals are the best available information to be used for wind energy analysis.

In this article, data from the Harrisburg, PA weather station were used. For the calendar years 1976, 1977, and 1978, the 3 hour interval wind velocities were used to determine the wind's energy potential. The N.O.A.A. data sheets give the wind velocity in knots (3 hour readings) and in mi/h (average daily and monthly values).

For the sake of analysis, a minimum start-up velocity of the wind turbine was taken to be 7 knots (about 8 mi/h or 3.6 m/s) and the maximum rated velocity as 22 knots (about 25 mi/h or 11.3 m/s). These values could be adjusted to suit any wind turbine model. This means that for wind velocities less than 7 knots, V = 0, and for velocities greater than 22 knots, V = 22 knots; the net area under the V^3 versus time curve when using Δt = 3 hours, becomes the numerical summation process $\Sigma([V^3 \text{ avg.}]\ \Delta t)$ using the average V^3 value for each Δt interval. For n values, the summation is:

$$\left[\frac{V_1^3 + V_2^3}{2}\right]\Delta t + \left[\frac{V_2^3 + V_3^3}{2}\right]\Delta t + \ldots\ldots + \left[\frac{V_{n-1}^3 + V_n^3}{2}\right]\Delta t \qquad (4)$$

which expands to equal:

$$\left[\frac{V_1^3}{2} + V_2^3 + V_3^3 + V_4^3 + \ldots\ldots\ldots + V_{n-1}^3 + \frac{V_n^3}{2}\right]\Delta t \qquad (5)$$

For a complete month, January for instance, there are 249 wind velocity values, the first for Jan. 1, 1 A.M., and the last for Feb. 1, 1 A.M.

Using this method, and a density of 1.23 kg/m^3 for air, the estimated monthly available kinetic energies per unit area were found. These are plotted in Figure 1. for the three years. Also shown is an attempt to estimate the available energy, using monthly average velocity values. For the three given years, a factor of 1.91 was determined when comparing the available energy using Δt = 3h to the energy available using Δt = 1 month. With this factor and 16 year monthly average wind velocities, the fourth curve was plotted. This curve would represent a long range average expectation of available energy and would be useful in an economy study. These values, when multiplied by the efficiency η, and the sweep area, $A(m^2)$, of a particular model of wind turbine, will give the estimated monthly energy output (kWh/mo.).

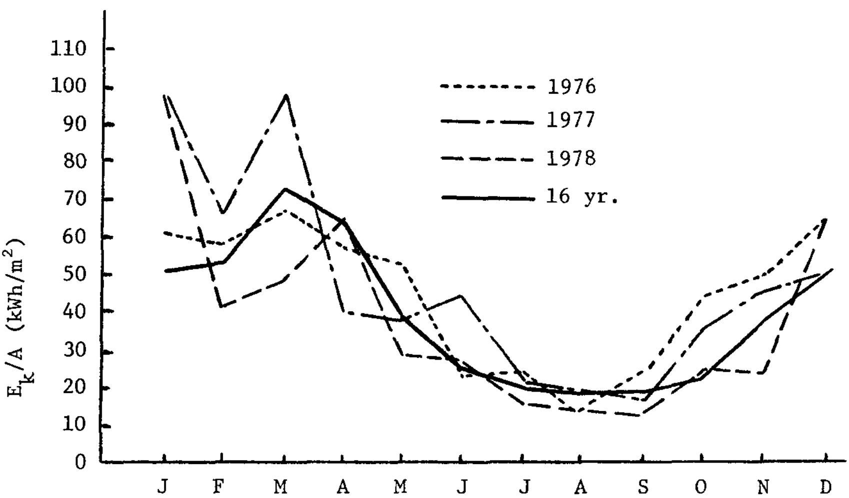

Fig. 1. Estimated Monthly Available Kinetic Energy Per Unit Area for Harrisburg, PA.

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WIND ENERGY CONVERSION IN THE MW RANGE

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EXTENDED ABSTRACT

The purpose of this paper is threefold: (a) to suggest that certain wind paterns above the Continental United States are particularly suited for production of electrical energy utilizing wind powered stations in the MW-Electric range (b) to describe a system specifically designed for such stations and (c) to present calculations which show that such a system is within the range of existing technology (with relatively low developmental effort required). In such a system the degree of utilization is much higher than tower supported conventional horizontal axis wind generators operating at heights up to 100 meters.

A windflow patern which exists in the air space over the continental United States, has been identified, studied and named the " Low Level Jet " [1] The low level jet is prevalent over large parts of the United States east of the Rocky Mountain range, in New England, off the New England coast and east of the Appalachian range. In the low level jet the average wind speed is 2.0 to 3.5 times higher than the corresponding wind speed at the 100 meter level and it occurs at heights from 200meters to 1000 meters. In addition these winds are subject to less diurnal and seasonal change. It is estimated that the " utilization factor " should be above 75% compared to 20-30% for the horizontal axis generators operating in heights up to 100 meters.

To take advantage of the very desirable features of the low level jet for wind energy production a wind energy conversion system was designed and patented [2,3]. This system consists of several wings which may be boyant and which are designed : (a) to utilize drag and lift forces on the wings for the production of energy (b) to be played out at the altitude of the peak wind velocity (c) to be retracted at a low resistance position and at a low velocity altitude (d) to make the necessary adjustments of height to maximize the energy production of the run, both in the energy production and in the retraction part of the cycle (e) to self compensate for atmospheric temperature-pressure variations and rain or ice deposition on the surface of the wings and (f) to self protect the system for maximum wind speeds or lightning. The essential features of such a system for a reference design of 2 MW have been calculated. The size and the exact shape of the wings depends on the mix of the drag-lift coefficients to be utilized. Sufficiently adequate knowledge exists in allied technologies as for example in aircraft wing design or burge towing cable design for the problems posed by the proposed wing. Similarly there exist materials in the current engineering practice to fill the needs of the proposed design.

Excluding developmental costs a detailed comparison shows that because of (a) the larger size of the proposed units (b) the higher energy density

(KW/unit area) of the wind at the low level jet altitudes and (c) the higher frequency of these winds (higher degree of utilization of the installation) the expected cost of the electrical energy to be produced will be significantly lower than tower supported horizontal axis machines.

The environmental effects of such systems are comparable to the conventional horizontal axis machines for aesthetic, wind patern modification or FM and television reception interference. There is, however, one notable difference e. interference with low flying aircraft. The applicable FAA regulations e not been investigated, however, several measures can be taken to alleviate this difficulty : (a) install the usual aircraft warning devices (b) determine an exlusion sphere and (c) keep such installations away from airport sites and aircraft routes. The possibility of installation over shallow bodies of water (lakes or off the coast) presents the possibility not only of avoiding aircraft routes but also minimizing land use costs and minimizing other aspects of the environmental impact.

In view of the many promising aspects of this system it is concluded that it should be investigated and developed further.

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THE CHARACTERISTICS OF TWO, SIMPLE, AUTOMATIC SPEED-CONTROL DEVICES FOR HORIZONTAL AXIS WIND-TURBINES

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EXTENDED ABSTRACT

INTRODUCTION

The need for speed-control devices, to prevent rotor overspeeding in strong winds, is examined and the features of classical blade-feathering systems for horizontal axis wind-turbines are reviewed briefly. It is explained that blade feathering tends to become complicated and costly when applied to medium and low speed machines because of the large number of rotor blades involved and secondly because of the loss of rotor rigidity associated with such an arrangement. It is also explained that medium and low speed machines find application for such tasks as the direct drive of water pumps etc., a form of load for which a high torque is usually required at zero rotor speed in order to ensure successful start-up under load.

After first discussing the advantages, and problems, of building slow or medium speed turbines sufficiently robustly to withstand gale force winds head-on, a concept acceptable in principle for specific forms of load, two distinct, automatic, speed-control systems are described. Each has been tested, in model form under laboratory conditions, in a wind tunnel. The model turbines used for these tests, which were each of 15½" (394 mm) diameter, were of the delta-wing bladed type [1]. The second speed control system has also been incorporated in a much larger unit featuring a delta-wing bladed turbine of 130" (3.3 m) diameter driving a d.c. generator.

DELTA-WING-BLADED TURBINE

The tests of the two speed-control systems were carried out using delta-wing bladed wind-turbines because this turbine type is a fairly efficient and structurally very simple, medium speed unit the aerodynamic performance of which is fairly extensively documented. Considerable performance testing has been carried out using model rotors of 15½" (394 mm) diameter [1]. Additionally, an optimized version of 130" (3.3 m) diameter, equipped with a dynamometer, has been tested in the 30' x 30' (9.2 m x 9.2 m) wind tunnel, of the National Research Council of Canada, at Ottawa. The maximum power coefficient attained during these tests was 0.37 at a velocity ratio of 1.5, the runaway velocity ratio was 2.8. It was also found that the torque coefficient was approximately constant, and a maximum, between a velocity ratio of zero and 1.2 [2].

SPEED-CONTROL SYSTEMS

One of the Systems tested was, in essence, a device for maintaining a substantially constant rotor speed in strong winds. The other system, which was less complex than the first, was an over-speed limiting device with an inherent capability of giving a measure of speed control allowing some use to be made of strong winds.

Constant-Speed System. This uses a governor-like arrangement to deflect the tailvane of the wind-turbine, via a mechanical linkage, in such a manner that the head of the machine precesses about a vertical axis hence becoming inclined to the oncoming flow. It is shown, from the results of model tests, that this system is functionally satisfactory but cannot serve as a shut-down device to bring the rotor completely to rest under violent storm conditions. It also has the disadvantage of incorporating some relatively precise components and hence tends to be comparatively costly if applied to simple low-cost wind-turbines.

It was also found that it was essential to incorporate a hydraulic (or equivalent) damper to prevent the system developing oscillations.

Over-Speed Control. This system utilizes the wind generated axial force, or end load, on the rotor to precess the head of the wind-turbine in such a way that the unit becomes inclined to the flow. It is shown, from the results of model tests, that this system, which incorporates a very simple mechanism, cannot be regarded as a satisfactory means of guaranteeing a constant rotor speed but can effectively prevent rotor overspeeding. It also has the feature that if the wind speed exceed a prescribed value, the rotor is brought to rest automatically. It is also shown that restarting is automatic when the wind speed drops below a threshold value.

The tests demonstrated that this device, which utilizes a variable restoring moment generated by raising a weight attached to a lever, permitted continued operation of the turbine up to wind speeds double that at which the control system cut in. It was also found that the system was operable, automatically, over the complete operating range of the wind-turbine from the unloaded (runaway) condition to a simulated overload condition with the rotor locked against rotation.

It is also shown that this speed-control system is, unlike the first system, fail-safe under almost all conceivable failure modes of the wind-turbine and load and also of the control system itself. Most of the conceivable failures of the control system itself result in premature feathering of the turbine. It was found that a hydraulic, or equivalent, damping device is desirable to prevent sudden operation of the control system under gusty conditions.

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AN ANALYSIS FOR AERODYNAMIC PERFORMANCE OF THE VERTICAL AXIS "ϕ" TYPE ROTOR WIND TURBINE

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EXTENDED ABSTRACT

INTRODUCTION

On account of the simplicity of the structure and ease of manvfacture, consequently the low cost of the set, the vertical axis "ϕ" Type rotor wind turbine (Darrieus Turbine) has attracted more and more attention in the world. In spite of the fact that there have been a lot of prototypes and experimental data of the Darrieus Turbine in many countries, a simple computing method, considering both aerodynamic performance of the adopted airfoil and the shear effects of the wind are considered will be quite useful to the wind turbine designers.

In this article, a multi-stream-sheet computing model is proposed (Fig.1). Because of the adoption of integral equation and a few engineering approximations and the introduction of an equivalent solidity of the blading $\sigma_1 = \frac{Nc}{r}\cos\beta$ and an equivalent velocity ratio $X_1 = \frac{\Omega r}{V_\infty \cos\beta}$ the solution of the equation are much simplified and more suitable for calculation of stream sheets in any positions. In this solution the wind energy efficiencies "ζ" with respect to different values of "σ_1" and "X_1" are obtained, and the aerodynamic performance of the whole wind turbine are determinted very easily, regardless of the shape of the rotor and the shear effect of the wind.

ANALYSIS

For a certain stream-sheet, the velocity and force diagrams are shown in fig.2. From the airfoil theory, the lift force acting on the differential length of the blade is given by:

$$dL = c \cdot C_L \cdot \tfrac{1}{2}\rho W^2 \cdot ds \qquad (1)$$

and the drag force is given by

$$dD = c \cdot C_D \cdot \tfrac{1}{2}\rho W^2 ds \qquad (2)$$

Since that the angles of attack in almost all operating regions are very small and always less than α_{stall} therefore we get:

$$\sin\alpha = \frac{1-a}{X_1}\sin\theta$$

$$C_L = \left(\frac{dC_L}{d\alpha}\right) \cdot \alpha \approx \left(\frac{dC_L}{d\alpha}\right) \sin\alpha \qquad (3)$$
$$C_D = C_{D_0} + K \cdot \alpha^2 \approx C_{D_0} + K \sin^2\alpha$$

where $a = a(\theta)$ is the factor of influence. When the wind turbine rotates a whole circle, the work output of the unit length of the blade is given by:

$$\frac{dP}{dZ} = 2\int_0^{\pi}\left[\left(\frac{dL}{dZ}\right)\sin\alpha - \frac{dD}{dZ}\right] r \cdot d\theta \qquad (4)$$

On the other hand, from the Glauert's axial momentum theory, the work output by the turbine for one cycle is

$$\frac{dP}{dZ} = 8 \cdot r \rho \frac{V_\infty^3}{\Omega} \cos\beta \int_0^{\pi} a(1-a)^2 d\theta \qquad (5)$$

Substituting the equations (1).(2) and (3) into (4), letting its result be equal to that of equ. (5), and assuming the factor "a" having the form of a=Asin , we get the main equation:

$$b_0 + b_1 A + b_2 A^2 + b_3 A^3 + b_4 A^4 = 0 \qquad (6)$$

where
$$b_0 = \frac{1}{8}\left(\frac{dC_L}{d\alpha} - 3\right)\frac{\pi}{2}(1 + x_1^2)\left(1 - 2C_{D_0}x_1^2/\left(\frac{dC_L}{d\alpha} - 3\right)\right),$$
$$b_1 = -\frac{1}{3}\left(\frac{dC_L}{d\alpha} - 3\right)\left[2 + x_1^2\left(1 - \frac{3}{2}C_{D_0}/\left(\frac{dC_L}{d\alpha} - 3\right)\right)\right] - 2x_1/\sigma_1$$
$$b_2 = \frac{\pi}{8}\left(\frac{dC_L}{d\alpha} - 3\right)\left[\frac{9}{4} + x_1^2\left(\frac{3}{8} - \frac{1}{2}\cdot C_{D_0}/\left(\frac{dC_L}{d\alpha} - 3\right)\right)\right] + \pi x_1/\sigma_1$$
$$b_3 = -\frac{8}{15}\left(\frac{dC_L}{d\alpha} - 3\right) - \frac{4}{3}\cdot x_1/\sigma_1$$
$$b_4 = \frac{15\pi}{384}\left(\frac{dC_L}{d\alpha} - 3\right)$$

Solving this equation for different values of σ_1 and x_1 , we obtain $A = A(\sigma_1, x_1)$ and $\zeta = \zeta(\sigma_1, x_1) = \left(\frac{8}{\pi}A - 4A^2 + \frac{16}{3\pi}A^3\right)\cos\beta$ (7) directly for the stream sheet in any position.

CALCULATIONS AND RESULT

With the method mentioned above, the wind energy efficiencies for diferent axial positions can be obtained. For small values of X_1 , there are some regions, in which $\alpha > \alpha_{stall}$, so that the corresponding part of the reduced work output must be deducted from the work output found by equ. (4). A table and a curve prepared by the author for the reduction factor of work done κ with respect to velocity ratio X_1 are shown in fig.3. The aerodynamic performance of the whole rotor is the sum of the efficiencies of all stream sheet; i.e.

$$\zeta = \frac{\Sigma\, \zeta_i \cdot \kappa \cdot \Delta A_i}{\Sigma\, \Delta A_i} \qquad (8)$$

The relative eff. Cp and the factor of torque C_M will be obtained as

$$C_p = \frac{27}{16}\zeta \qquad (9)$$

$$C_M = \zeta / X \qquad (10)$$

It should be noticed that in the whole calculating process, the identity of the values of V_∞ in various stream sheets is unnecessary, so that the shear effect of the wind can be considered easily, if it exist.

The experimental data of the rotor of the Sandia Laboratory with 2 m. diameter correlates very well with the results calculated by this method, it shows that this method is quite acceptable.

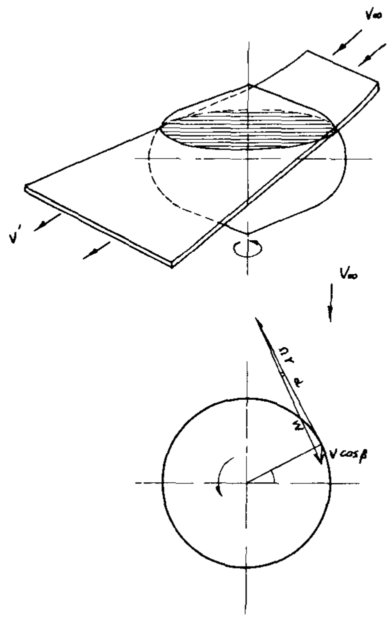

Fig.1. Stream-sheet of the "ϕ" Type Rotor

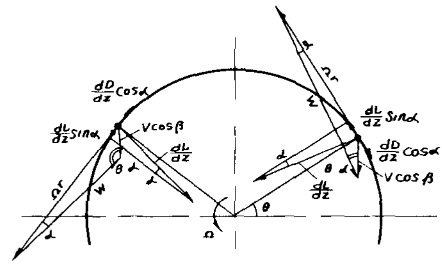

Fig.2. Velocity and force diagram of a stream-sheet

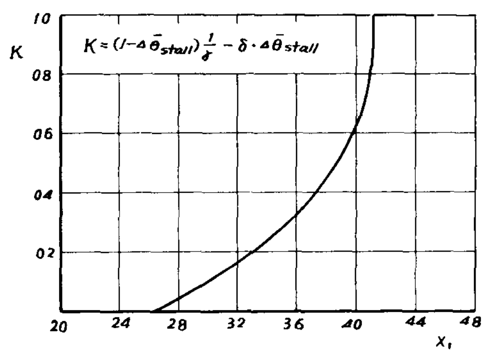

Fig.3. K-X_1

YD

A NEW CONCEPT IN HORIZONTAL AXIS WIND TURBINE ROTORS

V.P. Roan

For centuries people have had the capability of designing relatively effective wind machines. However, to achieve high power coefficient levels with horizontal axis machines, it has been necessary to utilize contoured rotor blades. This has meant a separate, expensive, rotor blade design and construction for each application.

A new concept has been developed at the University of Florida whereby the rotor blade is constructed of segments separated by aerodynamic fences, which may be individually oriented to achieve the same effect as a continuously contoured blade. The advantages are obvious. Segments may be made from inexpensive, light weight material and "sandwiched" on the rotor blade shafts in different numbers and various orientations to allow the same basic components to be used for entire families of wind turbines.

Several prototypes have been built and tested at the University of Florida, including a 14 foot, 3-bladed, 2 kilowatt system which won the international SCORE Energy Resource Alternatives II Competition in the wind division in 1977. Development of this device has continued using a moving test bed mounted on a truck body. Both power coefficient data and projected economics have been favorable for the concepts involved in this wind machine.

TURBO - ELECTRIC AND TURBO - PUMP

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EXTENDED ABSTRACT

DESCRIPTION

It is a three - bladed vertical turbine entirely inoxidizable (alloying of aluminium - stainless steel). The turbine drive a current - generator (or a pump) which is a two or three phase alternator with permanent magnets and an electronic regulation with an automatic limitation of tension. Than it charges long - lived battery Pb.

They are different models with power between 15 W and 300 W under tension of 12 V to 48 V.
This turbine has an efficiency based upon the total energy in the intercepted wind of around 40 %. It charges battery in winds with velocities below 5 miles per hour (8 km/h). Its energy balance E prod./E cons. becomes balanced in less than 2 years (E prod : production of the windmill/E cons. : consumption for its manufacture).

APPLICATIONS

Detached Houses

(Principal or secondary residence, refuge in mountains,...)

D[illegible] autonomy from 0,3 KWH to 4 KWH according to the model
Aesthetic and environmetal impact considered without any nuisance.
Storage in long - lived battery (100 - 200 ah/12 V - 24 V) :
direct lead for lighting (transitored light fitting 13 W), refrigerator, pump, TV,... and use of a converter for all domestic appliances 220 V AC.
In the Caribbean, no heating and cooking with gas.

Signalling

*(coastal or harbour signalling, buoying or providing with ground - lights)
Stations with fixed light (transitored lights 13 W + reflector) or flash light (flash frequency of 1 to 10 seconds according to the application) with crepuscular command (engaging and disengaging automatic)
Fixed or flash - ligthing signal with double security, seen in a distance of 5 to 10 nautical miles. Autonomy of the station in the absence of wind : approx. 30 days.*

Telecommunication

*(Relay station for TV, radio, telephone, radio - beacon, radar,...)
On principle these stations are placed on the top of isolated hill : the windmill is a better solution than the generator because it does not require any maintenance.*

Supply of measure instruments and transmitter for detached weather center or station for volcanic supervision which are sometimes inaccessible.

Alarms and Rescue

Supply of any alarm against fire, robbery, inundation,... or rescue fitting.

Pump

*The turbine drive directly an immersed pump with double membrane (insensible to abrasive sand) through a transmission stem guided by nylon - bearing inside the mast and the unit of depth.
Turbo - Pump alow to pump water till 155 feet (50 m) and from wind velocities of 6 miles for hour (10 km/h). In the Caribbean, with the middle annual wind (25 km/h), the quantity of pumping water for day is :*

20 m3/day with depth of 30 feet
10 m3/day with depth of 60 feet

CONCLUSION

Three years of multiple tests either on the top of Caribbean Volcanos (see fig. 1) in hard climate with sulphur atmosphere and frequent wind of high velocity (until 100 m/h) or on the top the Alps (see fig. 2) in Europe with the violent wintry weather have shown the adequate choice of the vertical turbine. Not only that but also the thousands of applications all over the world have allowed to perfect a simple, robust and reliable windmill - destined to sites distant from the grid or to developing countries.

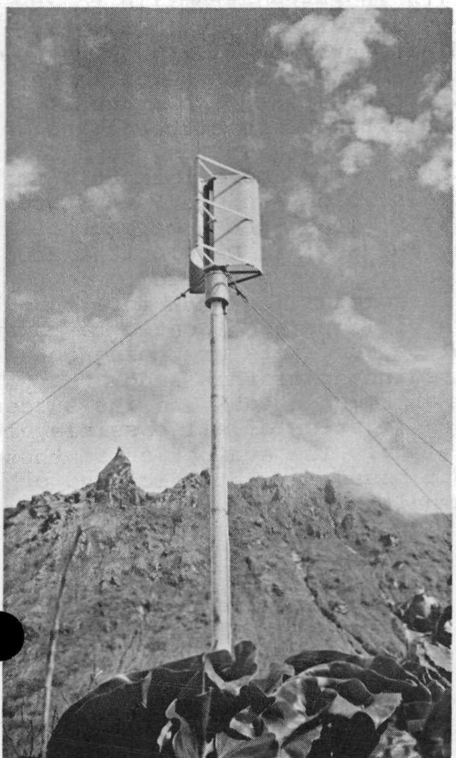

Fig. 1 Station for volcanic Supervision in la Soufrière (Guadeloupe)

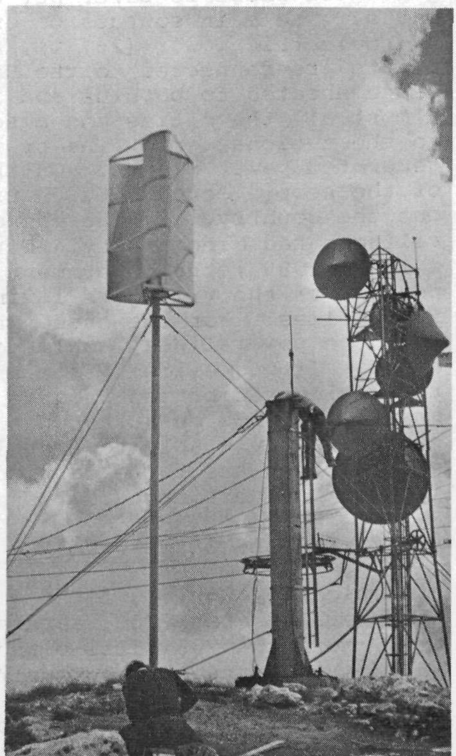

Fig. 2 Relay station of PTT in France

RURAL ELECTRIFICATION:
A CASE STUDY FOR WIND ENERGY IN IRAN

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EXTENDED ABSTRACT

1 - INTRODUCTION

Iran, with a vast reservoir of fossil fuel, has been expanding its electrical power generation capacity at an average rate of 21.6 percent for the past five years. For the same period, the generated electric power per capita increased from 110 to 209 watts. The main sources of energy are: fossil fuel (52.1%), Hydroelectric power (26.7%), and gas turbine (21.2%). The power plants are connected to the National Power Lines which in turn are connected to populus and industrial areas. As a result, almost all the cities and also small towns are either connected to the national grid line or in some cases have their own diesel generated power plants. On the other hand, more than 50 percent of the people occupy 66,000 villages which are scattered throughout the country. By the end of 1978, less than 6 percent of these villages had electricity. During the Seventh Development Program (1979- 1989) the government plans to take electricity to 80 percent of the villagers living in communities with more than 50 families. For the cases where villages are located far away from the power lines, small local power plants are being considered. It was evident from the beginning of this study that the rural electrification program is an immense task and its success greatly depends on a thorough investigation of all possible alternatives available to each locality. The evaluation of these alternatives has to be carried out based on statistics and other information pertinent to the communities.

2 - POTENTIALS OF WIND ENERGY IN IRAN

Historically, World's first wind turbine ever recorded was made and operated some 2200 years ago in Iran (then Persia). In addition, more than 50 multi-bladed wind turbines presently operate in various parts of the country for water pumping purposes.

Preliminary analysis of data obtained by the Iranian National Meteorological Organisation, and also collection and study of qualitative wind characteristics in many regions of the country reported by native people and partly found in old literature, suggest that many areas with reasonable level of wind energy exist in Iran. Particularly, it is estimated that most areas surrounding the two great eastern deserts (Lut Desert and Kavir Plain), such as Semnan, Bojnourd, Khaf, Yazd, Kerman, Zahedan, and Kashan, have wind energy levels which may exceed mean yearly averages of 150 to 200 watts/sq. meters. By an interesting coincidence, these regions are semi-arid areas of mainly agricultural character, with underground water reserves located at only 6 to 20 meters (20 to 60 ft) below the ground. Furthermore, they have low population density, are quite far from the national high voltage electricity network, are very far from oil fields or refineries, and have poor road connections to the rest of the country. These conditions, combined together, suggest that these areas make excellent candidates for utilization of wind energy as an economical way of rural electrification. This is more justified when considering the very high cost of transportation of fossil fuel the government will have to subside if local diesel or other conventional power plants were to be installed to produce electricity for remote villages in these areas.

Further cost analysis of different methods of rural electrification has proven that, depending on the size of the Wind Turbine Generator (5 and 25 kw. units were studied), the cost per kw. of electricity produced by conventional fossil fueled systems can reach or exceed 2.5 Rls/kwh. which is that produced by WECS's for, and pertinent to local wind conditions of, these regions.

3 - GHAZVIN PLAIN APPLICATION - ORIENTED PROGRAM

As a result of this preliminary study, the role of wind energy in the rural electrification program can be substantial. Therefore, a thorough investigation (a mission analysis) is proposed. As an important part of this investigation, an "application - oriented" test program is suggested and Ghazvin Plain, situated 130 km. (80 miles) west of Tehran was chosen for this purpose. The selection of this region is due, in addition to it being known as a windy area, to its proximity to the main research and administrative center of the country, its fast access to Tehran via freeway, and also because extensive data on wind characteristics, there, had already been collected. It is downstream of a bottleneck relating high pressure areas North of Alborz Mountains to low pressure desertic inland areas and, therefore, is subject to fairly permanent winds of 5 to 8 m/s. Further analysis of the available data indicated the existence of a region with mean wind energy levels of more than 200 watts/ sq. meters. More specific statistics on the socio-economic situation of 18 villages in this region indicated, among other things, that a sample village in this area needed 200 kwh/year per family of energy for electricity and water pumping. As a result, it has been suggested that sample Wind Energy Conversion Systems of medium (5 kw.) size be installed in this region in order to further elaborate on the advantages and also of the social, economical, and technical problems of introduction of such systems in the Iranian rural communities.

This program, when carried out, will also provide a basis for further evaluation of the rural electrification program in general.

COMMERCIAL, OR USABLE, SIZE CAMPBELL CHINESE TYPE WINDMILL

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EXTENDED ABSTRACT

At the 1st Miami International Conference on Alternative Energy Sources in December 1977 the author presented a paper describing a model of the Campbell Chinese Type Windmill which was not large enough for commercial use. Since the above conference the author has gone forward to design and build a commercially usable model in order to help carry this project through to a proper conclusion.

At the start several important design decisions were made as follows:

1. The entire windmill will be designed to withstand wind velocities up to 60 miles per hour (26.8 meters per second). On top of this a factor of safety of 2 will be applied.
2. Consistent with the above strength requirements, the entire design will aim at lowest possible weight. This will be done in order to help keep production cost as low as possible.
3. Starting with the sails, the so-called heart of the system, each sail will have a width of one meter (39 inches). For each sail the height over width ratio, H/W, will equal 7. On the previous model this ratio was 4. From careful observation and thought, the H/W ratio should be theoretically as large as possible, limited only by other design considerations, such as providing adequate strengths. Thus, the height of each sail will be seven meters (22.75 feet).
4. The entire windmill including the supporting structure will be able to pivot easily either up to the vertical, or operating, position or down to the horizontal, or protected, position. The horizontal position, in addition to having the ability to protect from destructive velocity winds, will make it much easier to install sails and to perform certain otherwise difficult maintenance functions. The pivot bearings at the bases will be offset sufficiently to keep the sails properly above the ground when in the horizontal position. The stop-operation mechanism of the previous model will not be included. The windmill can be stopped by lowering it to the horizontal position.
5. Intrigued by the idea of having more than one windmill supported in a row, the decision was made to mount two windmills on one supporting structure. Therefore the complete windmill will actually consist of two individual windmills. These windmills will be connected through the gearing and shafting so that they both contribute energy for rotating the single alternator group. Since the windmills will be connected together mechanically, one windmill will be positioned 60 degrees ahead of the other windmill. This should help provide a more uniform rotational velocity. Both windmills will rotate in the same direction. All sails will be alike.
6. The entire windmill will be easily disassembled and transported.

Portions which are extra long, such as sail frames, masts and the central rotating structure will be made in two or more sections and bolted together.

7. On this particular model provision will be made for mounting up to six automotive alternators. These alternators will function as a group to mechanically load the windmill and to generate the desired electricity. This mechanical load for the windmill will be torque. The torque of an alternator varies directly with the dc voltage applied to its magnetic field coil. Only one of the alternators will be supplied with a continuously variable dc voltage to its field coil. All other alternators will be full-torque only, and they will be switched either completely on or completely off by applying 12 volts to their field coils. This alternator group with the proper controls will be able to provide a continuously varying torque from zero up to the maximum for the six alternators.

At the start the electrical system will be simple and consist of charging 12-volt storage batteries. The one alternator which is supplied with the varying voltage to its field coil will generate electricity with a correspondingly varying voltage. This alternator has been rewound to generate single phase rather than three phase alternating current. A variable transformer will be used to control its voltage so that it can be used for charging a 12-volt storage battery. The other alternators are rotated at the controlled rpm and they are supplied with a 12-volt field coil voltage. At present the controls are performed manually, but future plans call for an automatic control system.

Since the previous paper, an important advantage for the use of three sails has been observed. In review, this vertical-axis windmill has three equally spaced sails which function like three sailing boats on a circular course. Each sail tacks on the up-wind side, runs with the wind, jibes, tacks on the down-wind side and luffs. When each sail jibes, the expected jarring action does not occur. The sail behind it effectively acts as a shield, or wind break, for the sail doing the jibing.

In the building of this windmill the author has received assistance from a friend, Dalton James, and the windmill is erected in the back yard of the James' home in Orinda, California. Since the back yard has a 20-degree slope away from the house and one mast is down-hill from the other, the supporting structure has been adapted to this. A level mounting would have been much easier for the first windmill of the new design. The supporting structure with only one of the individual windmills installed for the initial testing is now in operation.

The initial testing of the one windmill will have two principal objectives as follows:

1. To determine the efficiency of the windmill.
2. To determine if this windmill can be controlled to operate at a preset

constant rotational velocity (rpm) in all the usable wind velocities without suffering any serious detrimental effects.

With the previous model the energy received per unit of time (horsepower) was calculated using a friction, or prony, brake. For this larger model the energy received in horsepower will be measured using rpm and torque. Rpm of the shaft which drives the alternators will be obtained by a magnetic-type sensor located at proper distance from a 60-tooth gear on the shaft. The instantaneous rpm will be read from a digital indicator. Reaction torque of the alternators will be obtained by using a lever attached to a pivotable base for the alternators. The outer end of this lever applies a force to a strain gage-type load cell, and this instantaneous force will be read from a digital indicator. Torque equals this force times the moment arm which is the length of the lever.

Previous observations with the older models have led to a conclusion that rpm of a Campbell Chinese Type windmill can be independent of wind velocity. For example, if the wind velocity increases, the windmill rpm will also increase. Then the torque load for the windmill can be increased to reduce rpm and restore it to its desired level. There appears to be no detrimental effects. If the tests will show that windmill efficiency is not adveresely effected and there are no other detrimental effects, this can be an important advantage particularily for the electrical generating portions of the system. It means that the voltage generated can be maintained constant at a desired level. It also means that the frequency of alternating current, such as 60-cycle ac, can be maintained constant at a desired level. No additional electrical equipment will be needed to accomplish the above.

The wind intercepted area for one windmill is a rectangle measuring 22.75 feet (7 meters) high by 5.6 feet (1.7 meters) wide. The intercepted area 127.4 square feet (11.8 square meters) is equivalent to a circular area having a diameter of 12.7 feet (3.9 meters). For the two windmills, when the wind direction is perpendicular to the plane of the support structure, the intercepted area is equivalent to a circular area having a diameter of 18.0 feet (5.5 meters)

The total weight of the windmill including fabricated steel bases and anchors is 2262 pounds. For this installation no concrete was poured. Using the diagram from the previous paper to obtain 1973 selling price. This diagram was adapted from "Wind Machines" by F. R. Eldridge, and was originally made by George Rosen while employed by Hamilton Standard Division of United Technologies.

1973 Selling price, dollars per pound	= $ 1.36
1973 Selling price	= $ 3077.

Assuming the inflation from 1973 to 1979 to be 50 percent,

1979 Selling price	= $ 4615.

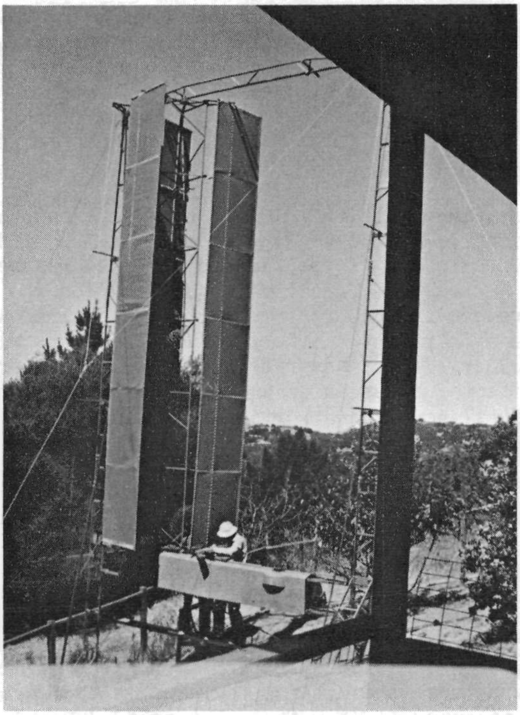

Fig. 1 - Campbell Chinese-Type Windmill

SESSION 6E

SYNTHETIC FUELS

ETHANOL FROM MUNICIPAL CELLULOSIC WASTES

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INTRODUCTION AND BACKGROUND

This paper addresses the use of municipal cellulosic wastes as a feedstock for producing ethanol fuels, and describes the application of enzymatic hydrolysis technology for their production. The concept incorporates recent process technology developments within the framework of an existing industry familiar with large-scale ethanol fermentation (the brewing industry). Cellulose is one of the world's most abundant organic materials which can be used as a source of food, fuel and chemicals. The net worldwide production of cellulose is estimated at over one hundred billion tons per year. From one ton of waste paper, about one-half ton of glucose can be produced and subsequently fermented to 78 gallons of ethanol. Conversion of cellulose to glucose can be accomplished by either acid hydrolysis or by enzymatic hydrolysis. Among the advantages of enzymatic hydrolysis is that the process takes place at moderate conditions so that the glucose yield is high and directly related to the weight of the cellulose used. Glucose syrups produced enzymatically are fairly pure and constant in composition.

CHARACTERISTICS OF THE BREWING INDUSTRY

In 1978, the brewing industry sold 162.4 million barrels (32 gallons/barrel) of beer and had a nameplate capacity of about 200 million barrels thus, about 37.6 million barrels of capacity were not utilized. Additionally, beer brewing is a seasonal industry with peak months of about 10% of capacity. About 40 million barrels additional could be made available from off-peak production capacity for a total additional capacity of 77.6 million barrels (for the year 1978). With a conversion factor of between 5 and 15 gallons of ethanol per barrel of beer, the total ethanol potential that could be supplied by the brewing industry, without impacting current beer production, is between 388 million and 1.16 billion gallons. Thus, ethanol produced from excess brewing industry capacity could satisfy 4% to 12% of a national market for a 10% ethanol/gasoline blend. The brewing industry is widespread and well distributed throughout the United States with operating breweries in 32 of the 50 states. As of June, 1978, there were 11 breweries which have become idled (thus exemplifying the current excess-capacity situation), mostly for reasons of economy. This is the result of an industry trend toward consolidation.

APPLICATION TO AN EXISTING BREWERY

In August, 1978, for reasons of economy, the Highlandtown (Baltimore City, Maryland) Plant of Carling National Breweries was consolidated into Carling National's Beltway Plant in Baltimore County. The Highlandtown Plant still contains fermentation, packaging and warehousing facilities which have remained essentially undisturbed. With modifications that would require basically the installation of enzyme production and ethanol distillation apparatus, the plant could be converted to ethanol production at a fraction of the expense required for a completely new plant. These modifications include the addition of enzyme production, cellulose pretreatment, hydrolysis processing, ethanol distillation and certain waste recovery equipment. Fermentation, materials handling, and storage equipment are essentially in place, as are portions of waste recovery equipment, all utility supplies (steam, electricity, water) and the physical housing structure. Labor is available and training requirements are minimal since brewing personnel are familiar with large-scale ethanol fermentation. Feedstock for the envisioned concept would consist of the cellulosic fraction from municipal solid wastes. Currently, about 4,200 tons of refuse are generated daily in the metropolitan Baltimore area. This amount is nearly ten times that needed to supply a converted brewery producing five million gallons per year of anhydrous ethyl alcohol. A resource reclamation facility currently operating in suburban Baltimore County (near Texas, Maryland) has the capability of processing about 1,500 tons of refuse per day to about 1,125 tons of highly cellulosic material per day. At this facility, the incoming raw waste is shredded and mechanically separated into various fractions--ferrous metals, other metals, residue, and a highly cellulosic material commonly referred to as RDF (refuse derived fuel). It is the cellulosic material or RDF that would serve as the ethanol feedstock for the proposed plant conversion concept.

Figure 1 illustrates the envisioned process by which ethanol can be produced from municipal cellulosic wastes. The net process thermal efficiency is estimated to be 17% and the gross (output ethanol to input RDF only) process thermal efficiency is estimated to be about 25%. Including the generation of medium Btu gas increases the net process efficiency to about 19%.

Ethanol (anhydrous) production costs are estimated at $1.09 per gallon (less profit) including all utility, maintenance, labor, materials and equipment amortization/depreciation costs. From Carling National's experience, it has been found that cost of producing salable byproducts (CO_2, distillers feed, etc.) is equal to or less than the income generated by their sale. Thus, byproduct production costs are conservatively estimated to equal sales revenues.

While a detailed engineering assessment has not been completed to date, preliminary findings and analyses (presented herein) indicate that the overall concept is feasible and warrants further study. As of this writing, the idle brewery alluded to in this paper has not undergone any modification or renovation to produce ethanol per the proposed concept.

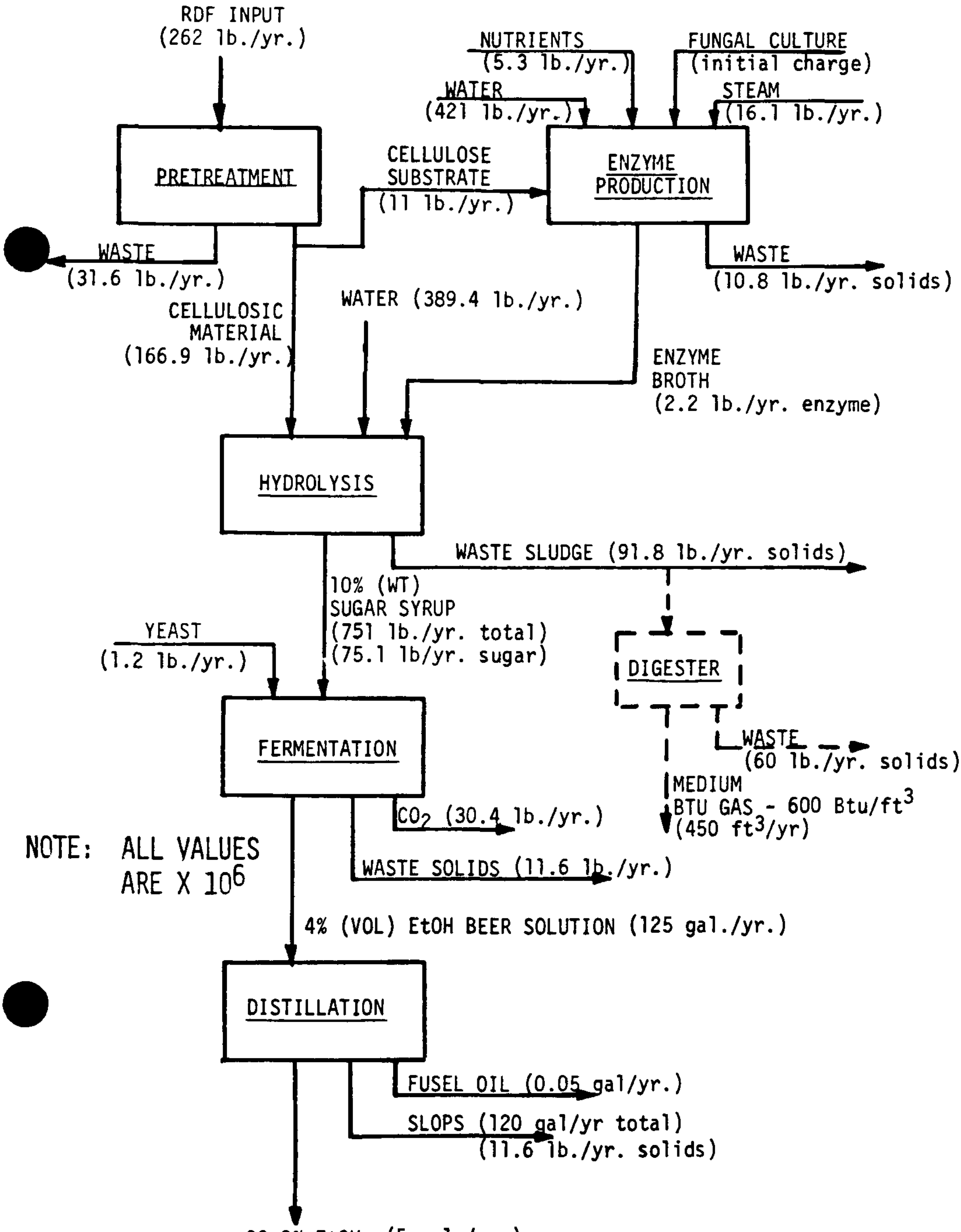

FIGURE 1, SIMPLIFIED PROCESS FLOW

SYNTHETIC FUEL PRODUCTION IN A PARTICLE-BEAM DRIVEN FUSION REACTOR

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EXTENDED ABSTRACT

INTRODUCTION

A projected particle-beam driven, inertial confinement fusion reactor [1] would ignite fuel pellets at the rate of ten times per second. A pellet energy yield of 75 MJ, coupled with the ignition energy, would produce an electrical plant output of approximately 303 MWe. Instead of using all the energy as thermal energy converted to electricity, one can use the initial ignition chamber thermal energy of about 24 MJ per pellet to drive endothermic chemical reactions in a buffer gas, producing synthetic fuel [1]. Most of the direct yield energy of the pellet (56 MJ) leaves the ignition chamber to be converted to thermal energy and would be used to produce electricity. The buffer gas must be pumped through the ignition chamber at a rate that will maintain a desired bulk temperature at some desired pressure. The rate required will be between 20 and 50 cubic meters per second for an operating pressure range of 2 to 10 atmospheres. For a bulk temperature of 2000 K or higher, the gas will be essentially stationary compared to the times required for chemical reactions to proceed to equilibrium. This allows thermodynamic equilibrium calculations to be performed for the various chemical reactions of interest for the production of synthetic fuels.

COMPUTATIONS

All calculations assumed thermodynamic equilibrium of the constituents of the gas mixture and used equilibrium constant values from the JANAF Thermochemical Tables. Rate constants and relaxation times, where computed, were calculated from partition functions for the various reactions. A prior survey [2] indicated that three particular reactions looked promising at high temperatures for the efficient production of synthetic fuels.

Water Vapor and Carbon Particles at 2000 K. Equilibrium computations show that this reaction produces 49.8 percent hydrogen and 50 percent carbon monoxide for operating pressures of 2 to 10 atmospheres. For a gas flow of 21 cubic meters/second at an operating pressure of 10 atmospheres, the output of synthetic fuel is about 100 and 1,400 metric tonnes/day for hydrogen and carbon monoxide, respectively. This equates to a potential power from the combustion of these chemical products of approximately 340 MWt. This is in addition to the electrical output from thermal conversion of the other available energy of approximately 244 MWe. Note that an examination has not yet been completed of the required quenching rates to retain high temperature equilibrium products in a transportable condition.

Water Vapor and Carbon Particles at 4500 K. Computations show that this reaction produces 17.2 percent carbon monoxide, 15.7 percent C_2H radical, and 7.75 percent atomic hydrogen. When quenched to room temperature in a one millisecond time period, the C_2H combines preferentially with the atomic hydrogen to produce acetylene, resulting in a final gas mixture of 50 percent carbon monoxide, 45.9 percent acetylene, and 4.1 percent hydrogen [3]. The carbon gases condense to carbon particles during the quench so only about 50 percent of the gaseous products at 4500 K remain at room temperature. The energy released during this process must be recaptured for conversion to electricity. For a gas flow rate of 8.5 cubic meters/second at an operating pressure of 5.25 atmospheres, the products are 43 tonnes/day, 0.3 tonnes/day, and 50 tonnes/day for acetylene, hydrogen, and carbon monoxide, respectively. This results in a power yield from chemical stored energy of 38 MWt. The additional electrical output would then be about 270 MWe.

Carbon Dioxide and Carbon Particles at 3500 K. Computer results show that this reaction produces 98.7 percent carbon monoxide with a balance of triatomic carbon gas. For an operating pressure of 8 atmospheres and a gas flow rate of 29 cubic meters/second, about 1,960 tonnes/day of carbon monoxide is produced. This corresponds to about 230 MWt from stored chemical energy. The additional electrical output is about 248 MWe.

EXPERIMENT

An experimental arrangement has been devised to test the computed behavior of the carbon dioxide and carbon particles reaction for a bulk temperature of 3500 K. This is done by impacting on argon plasma from a deflagration plasma gun ($n_e \approx 10^{15}$/cc, kT $\simeq$ 5 kev) onto a cloud of carbon particles intermixed with carbon dioxide gas. The bulk temperature is achieved by adjusting the amount of target material that the plasma must interact with. The Carbon Black particles range in size from 11 to 19 microns. The carbon particles and the carbon dioxide gas are introduced into the reaction volume via an electrically pulsed valving system. The amount introduced depends on the time and magnitude of the electric pulse to the valve, the carbon dioxide gas pressure in the valve chamber, the pressure in the target volume, and the quantity of carbon particulates in the valve chamber. Experimental measurements include trace amounts of gases present after the reaction, plasma behavior during the interaction, variations of carbon particle number densities during reaction and chamber pressure. A number of unresolved experimental difficulties have kept the measurements from being definitive, although work is continuing.

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BIOGRAPHICAL SKETCH

James W. Fisk has a B.S. in Mechanical Engineering from New Mexico State University and an M.S. in Nuclear Engineering from the Air Force Institute of Technology. His employment record includes work as a mechanical engineer at the Air Force Weapons Laboratory, Albuquerque, New Mexico, teaching engineering physics at the Air Force Academy, and work as a test and evaluation engineer with the Air Force at the White Sands Missile Range in Alamogordo, New Mexico. He is currently completing a Ph.D. in Nuclear Engineering at the University of New Mexico in Albuquerque.

David M. Woodall received a B.A. in Physics from Hendrix College, Conway, Arkansas, and an M.S. in Nuclear Engineering from Columbia University. After employment as a nuclear core design engineer with Westinghouse Nuclear Energy Systems in Pittsburgh, he returned to Cornell University for a Ph.D. in Applied Physics. He has been an Assistant Professor at the University of Rochester, where he worked in laser fusion with the Laser Energetics Laboratory of the University. He is currently an Associate Professor at the University of New Mexico, where he is actively involved in many phases of controlled fusion research.

fwt

PRODUCTION OF LIQUID FUELS WITH A HIGH TEMPERATURE GAS COOLED REACTOR

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EXTENDED ABSTRACT

The High Temperature Gas Cooled Reactor for Process Heat (HTGR-PH) is a high temperature version of the electric power producing reactor that uses graphite as a moderator and helium as a coolant. The impetus for nuclear energy as a source of process heat comes primarily from the current fossil-fuel situation. The fossil-fuel shortages and escalating costs have provided the incentive for developing a nuclear process heat source and an increased interest in synthetic fuels. The desire for energy self-sufficiency in the longer term has put stronger emphasis on the more plentiful domestic energy sources; both coal and nuclear fuels. One of the advantages of the nuclear heat source is that the nuclear-chemical fuel factory can reduce or avoid the release of carbon dioxide into the atmosphere.

The HTGR-PH can also be coupled to a chemical process utilizing coal whose product is syngas (H_2 + CO) or hydrogen. The syngas or hydrogen can be used to produce liquid fuels such as methanol or ammonia which can be economically stored or transported over long distances by pipeline. The hydrogen can be used for synthesis of ammonia and, with CO_2 available from the reforming process, urea. Following transportation from the large, centralized "fuel factory" to smaller outlying demand centers the methanol or ammonia can be burned in gas turbines (or reacted in fuel cells) to cogenerate power, can provide local process/district heat, and can be used as chemical feedstocks.

From a market standpoint, the most readily acceptable synthetic fuel would be one that is directly substitutable for current liquid fuels; e.g. diesel, jet fuel or gasoline. These fuels can be made from coal, basically by the addition of hydrogen. Two basic routes have been identified, direct and indirect. The direct route starts with a coal liquefaction step and then upgrades the basic product by hydrotreating.

In the coal liquefaction process a portion of the product is methane. This methane can be reformed with steam to produce the hydrogen required for the coal upgrading. The coal liquefaction step can be done by a number of different processes such as SRC II, Donor Solvent or H-Coal. These processes are currently in the development stage. Upgrading involves hydrotreating with processes similar to oil refining. The indirect process utilizes a coal gasification step which produces a mixture of hydrogen, carbon monoxide and methane. This gas is used in a synthesis process to produce one or more liquid fuels.

the secondary system. The secondary helium is intentionally maintained at a pressure level near the primary helium pressure in order to minimize the long-term loading on the IHX, in which the combination of high temperature and material limitations requires a near-pressure-balanced operation for structural integrity.

The intermediate loop provides an additional boundary between the NHS and the process, thereby improving the plant safety and offering considerable flexibility for alternate applications.

During normal operation secondary helium is heated to 900°C (1650°F) in the IHX and routed outside the PCRV to the reformer and then to the steam generator, which extract the heat necessary for the process and auxiliary power generation.

In conclusion the production of transportation fuel from coal can be accomplished by two principal process routes. The HTGR-PH can materially improve the yields from either route by supplying the energy needed for the process. The replacement of the coal combustion to supply the process heat by a nuclear heat source substantially reduces the quantities of carbon dioxide, nitrous oxide, and sulfur dioxide produced. Additionally, the reactor can cogenerate electricity for outside use at high thermal efficiency.

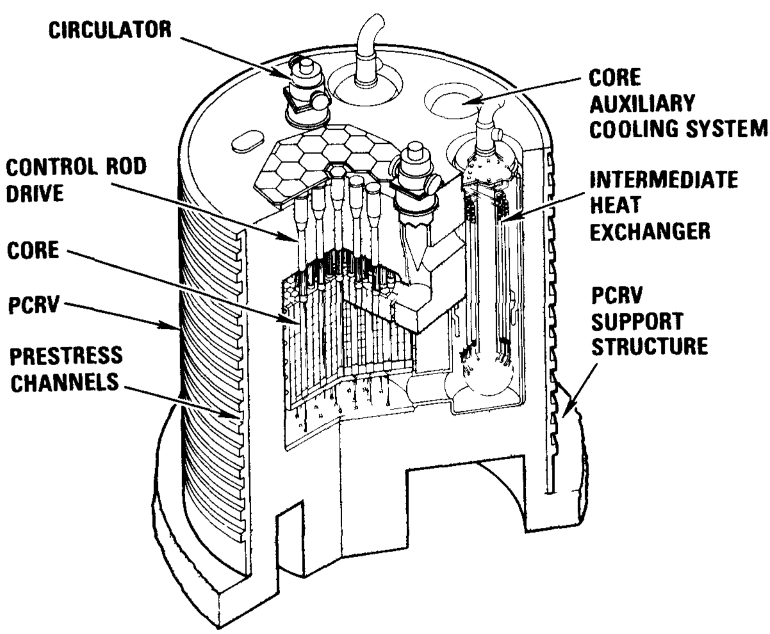

Fig. 1 - 842 MW(t) VHTR Arrangement

Additional methane is produced in the synthesis process. A recycle gas containing the methane is reformed to produce additional synthesis gas. This process has been in operation for many years at Sasol in South Africa utilizing a Lurgi gasifier and Fischer-Tropsch synthesis. Output is primarily gasoline. Other gasifiers such as Winkler could be used as well as other synthesis processes; e.g. Mobil (M) to produce either methanol or gasoline.

The HTGR-PH can effectively participate in both of these processes by producing hydrogen via steam reforming of methane and steam for both process and in-plant power. One of the advantages of the nuclear version is a considerably greater prpduct yield since the energy required for processing is almost entirely supplied by HTGR, not by the coal. For the coal liquifaction route, about 2.8 barrel/ton of coal is produced with a conventional process and 4.2 barrel/ton with nuclear. With the indirect process yields are increased from 1.9 barrel/ton to 2.9 barrel/ton.

Either the direct or indirect process route can be used to produce ammonia which can be considered either as a non-carbon liquid fuel or fertilizer. For this process, the carbon is used as the reductant of the steam, producing CO_2 and hydrogen.

The HTGR-Process Heat reactor that can provide the energy is a version of the HTGR developed for the production of electricity and in operation at Fort St. Vrain for Public Service of Colorado. As in other HTGR designs, the HTGR-PH reactor has its entire primary coolant system contained in a prestressed concrete reactor vessel (PCRV) which provides the necessary biological shielding and pressure containment. The high-temperature nuclear thermal energy is transported to the externally located process plant by a secondary helium transport loop. In addition to providing the thermal driving potential required for the process, the nuclear heat is also used to generate high-temperature, high-pressure steam to satisfy both the process and electrical generation needs for the operation of the nuclear plant and process plant.

The current plant design utilized in steam-methane reforming has a core thermal power rating of 842 MW(t) and a reactor outlet temperature of 950^{o}C. An isometric drawing of the HTGR-Process Heat reactor is illustrated in Fig. 1. The hot helium is collected in a plenum area beneath the core and manifolded to the two IHX units situated inside cavities beside the core. The primary helium flows upward through the IHX cavity, countercurrently transferring heat to the secondary helium. The cooled primary helium leaving each IHX is then ducted to its respective circulator, which returns it to the inlet plenum above the reactor core at 475^{o}C (887^{o}F).

The secondary helium system (or secondary loop) transports thermal energy from the IHX to the process plant. Because leakage within the IHX can result in direct communication between the secondary and primary circuits, the secondary helium pressure level is set slightly higher than that in the primary circuit. This prevents possible leakage of the reactor helium into

THERMODYNAMIC CALCULATIONS FOR OTTO CYCLE ENGINES USING METHANOL AS A FUEL

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INTRODUCTION

Methanol is currently of considerable interest for use in automobiles as an alternative to petroleum based fuels. The technology required for its utilization is very similar to that for gasoline hence storage facilities and handling procedures as well as service station and vehicle hardware need suffer little change. In addition to this compatability, methanol production from coal or renewable biomass is technically well developed so overall, it is probably the most attractive alternate vehicle fuel economically and politically, at least in the near term. Even in a hydrogen economy, methanol may find a place because it stores more hydrogen per unit volume than does liquid H_2 itself.

This paper examines some of the fundamental calculations conventionally used to predict the performance of Otto cycle engines. Comparisons are drawn with gasoline, and the thermodynamic reasons are pointed out for a number of the striking differences in the behaviour of the two fuels.

THERMODYNAMIC CHARTS FOR CYCLE CALCULATIONS

Charts of thermodynamic properties are frequently used in Otto cycle engine calculations. They are available for gasoline of various fuel-air ratios for both unburned mixtures and products of combustion. Texts such as those of Obert [1] or Lichty [2] describe their use in detail and include copies for commonly used mixture strengths. Starkman, Newhall and Sutton [3] published such charts for methanol and several other non-petroleum fuels. Like the usual gasoline charts, their compressed fuel-air mixture data is only valid for completely vapourized fuel; however, unlike gasoline, for which the presence of liquid fuel during compression has only a small influence on the result, methanol's high heat of vapourization may profoundly change the outcome. Equations are derived to permit calculations for the compression of a 2 phase mixture of air, gaseous fuel and liquid fuel droplets. The equations may be used to determine the point during compression at which vapourization is completed and the work done on the mixture up to that state. The remaining portion of the compression process is then calculated in the usual manner using the Starkman charts. The effect on overall compression work and hence power output and efficiency is shown to be substantial.

Reed and Lerner [4] suggested that methanol dissociation to carbon monixide and hydrogen during the compression process could account for some of methanol's combustion characteristics. If it occurred, such dissociation would greatly change the mixture properties ard the use of the Starkman charts would then be questionable. However, Hilden and Stebar have shown experimentally that this dissociation does not occur and hence the published equilibrium charts may be considered valid within the usual limits.

EFFECTS OF EVAPORATIVE COOLING ON INDUCTION

Calculations of the adiabatic temperature drop in the intake manifold due to methanol evaporation as great as 142K have been published It is shown that cooling to this extent is not thermodynamically possible because of the reduction in vapour pressure during the cooling process Maximum theoretical adiabatic cooling is calculated and shown in graphical form The effects of partial or complete evaporation on the energy of the induced mixture are shown and their influence on maximum power output is discussed

COLD STARTING PERFORMANCE

Cold start characteristics are compared for gasoline and methanol The reason for the poor cold weather performance of methanol can be found in the effect of the large enthalpy of evaporation. It is shown that the reaction of the two fuels to the choke is different because the physical phenomena involved are not the same. For this reason the choke is much less effective for methanol. The influence of vapourization rate is calculated and also shown to be a significant factor in its poor cold performance Manifold heat requirements of the two fuels are compared These involve more than merely the latent heats and methanol always requires substantially more heat than gasoline Both maximum efficiency and best starting performance are to be achieved with a carburettor/manifold system rather than through fuel injection.

OTHER CONSIDERATIONS

Flame speed, flammability limits and exhaust gas recirculation are also considered insofar as they influence the efficiency, maximum power, and exhaust emission of methanol fueled Otto cycle engines

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CATALYTIC HYDROGENATION OF TURKISH LIGNITES TO OXYGEN FREE OIL & GAS

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EXTENDED ABSTRACT

INTRODUCTION

Lignites are compounds which contain carbon, hydrogen and oxygen as main elements and nitrogen and sulfur as hetero atoms. Being a low ranking energy resource, they are considered much below bituminous coal and above peat. Due to their high oxygen and inorganic materials content, they have very low heating values.

In this study, catalytic conversion of two distinct Turkish lignites (Elbistan and Beypazar) to oxygen free oil and gas was investigated in a rocking autoclave with hydrogen gas over nickel (in situ from nickel hydroxide) catalyst.

The high pressure studies from autoclave could be traced on micro-scale with the use of DSC (Differential Scanning Calorimeter) equipment.

RESULTS AND DISCUSSION

Inert (nitrogen) atmosphere was used for heating purposes. Thermal decomposition in inert atmosphere known as pyrolysis, involves some endothermic and exothermic cases.

Dehydration of moisture naturally present in lignites causes heat of absorption. Then the heat release due to condensation of carbon rings following the evolution of volatiles [1], and finally forming carbon rich semi-coke product.

The paraffin oil used in making lignite slurry served for two purposes. Having a high boiling point, it acted as a vehicle and also proveded a liquid medium for better contact.

Both liquid (hydroliquefaction) and gaseous (hydrogasification) products can be obtained from the catalytic reaction of lignite in hydrogen gas. The temperature (350^o, 380^o, 425^{o}C) and pressure 75, 120, 140 atm.) regions used in this study were within the desired limits of industrial preference.

The reaction mechanism is a set of first order unidirectional steps, first to oil and then to gaseous products with increasing reaction severity. The overall reaction can be summarized in the following way:

$$\text{Lignite} \xrightarrow[H_2/Ni]{\text{heat}, k_1} \text{Oil} \xrightarrow[H_2/Ni]{\text{heat}, k_2} \text{Gas}$$

Considering carbon is the main reactant, the reaction dependency was found to be first order. It was also found that reaction is first order with respect to catalyst loading although it becomes pseudo-zero order for increased (>3%) concentrations and approximates a zero order behaviour in hydrogen. These results are in well agreement with the ones found in literature [2].

Hydrogen gas facilitates the hydrocracking by forming smaller and stable hydrocarbons, also acts as an agent for the removal of oxygen from an oxygenated compound like lignite.

By catalytic reaction of lignites in hydrogen atmosphere, oils containing very low oxygen contents (<5%) and high heating values (11-12000 k-cal/kg) were obtained.

ACKNOWLEDGEMENTS

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AN EXPERIMENTAL INVESTIGATION OF MANNED VEHICLE UTILIZING CDE (CONCENTRATION DIFFERENCE ENERGY) ENGINE

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EXTENDED ABSTRACT

It is well known that, pure water is poured into dense sulfuric acid, sodium hydroxide, strong heat is generated instantly. This energy liberation is caused by the sudden change of the concentration of solution. In nature and industries, many similar energy phenomena related to the change of concentration of acid, alkalin and normal salts in various solution are existed, for example, like the generation of osmotic pressure, concentration cell and elevation of boiling point and depression of freezing point and heat of dilution etc. They are generally called of the concentration difference phenomena and energy liberated by the change of concentration of solution are called generally "concentration energy" or "concentration difference energy" in this paper [1]. In this report, the recent developments in the study of the CDE system & engine are reported, including selection of solution, & anti-corrosive materials, & experimental data of manned CDE vehicle are described.

EXPERIMENTAL APPARTUS

The experimental CDE vehicle #1 is shown in Fig. 1, which carries three reciprocating system engine equipped with 2 cylinders of double action type with 20 mm diameter and 20 mm stroke. This manned CDE vehicle #1 is driven for 20-30 mins. at the average travelling speed of 8 km/h by the CDE energy of 26 liters of LiCl aqueous solution & 6 liters of fresh water in the boiler soaked in solution with the temperature range of 163-142°C. The specifications of this vehicle are shown in TABLE I.

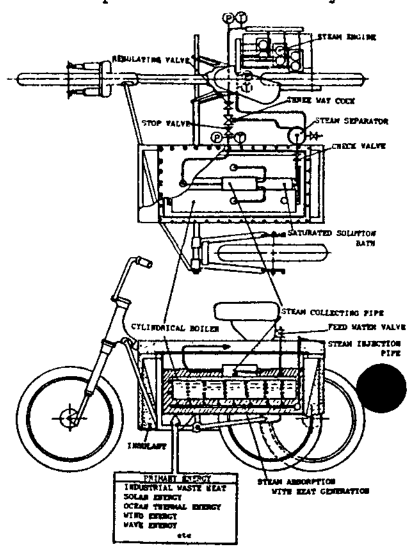


Fig. 1. A Cross-sectional View of Manned-CDE Vehicle No. 1

EXPERIMENTAL RESULTS

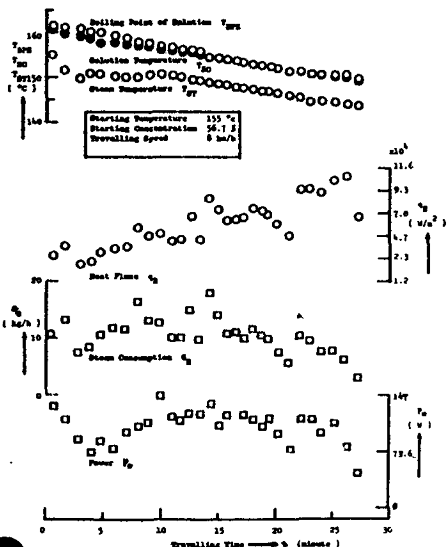
In Fig. 2, an example graph of experimental results of this vehicle is shown, which includes the records

of temperature, concentration and power, etc.,picked up from a typical batch data of the manned vehicle at constant travelling speed, where, the data of from boiling point of solution, and the steam temperature in the boiler is estimated from steam pressure, and the temperature distribution of boiler wall are measured with thermocouples.
It should be noted that the concentration of solution is dilutedas running time passes at the batch test, and the elevation of boiling point falls while steam temperature falls with 1 kW class CDE engine[2], characterizing the feature of CDE engine in batch running.

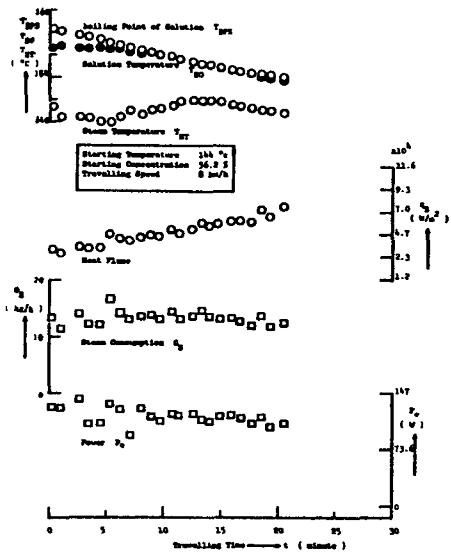
TABLE 1

SPECIFICATION OF MANNED CDE VEHICLE

Principal Items	
Used Salt	LiCl
Water Inventory	6 liters
Aqueous Solution Inventory	26 liters
Type of Boiler	Cylindrical Boiler
Temperature of Solution	163 — 142°c
Boiler Pressure	6 — 2.8 ata
Reciprocating Steam Engine	Stroke x Bore 20 x 20 Double Acting Twin Engine x 3
Power	0.6 kW Max
Travelling Speed	16 km/h — 4km/h
Travelling Time	20 minute — 30 minute
Complete Weight	156 kg



RUN. 6



RUN. 12

Fig. 2. Travelling Performance of CDE Vehicle No. 1

The data of over-all heat transfer coefficient α_{OV} (heat flux of boiling / temperature difference between boiling point of solution and steam temperature) of this CDE vehicle, is plotted in Fig. 3.
Markedly high α_{OV}'s, as high as 15 W/m^2°K are obtained.

MATERIAL of CDE SYSTEM

Its is necessary that materials used CDE system should have good quality of anti-corrosion and thermal conductivity, paticularly, their cost should be low enough for big scale energy storing material.
Therefore, for this system, comparatively anti-corrosive materials against LiCl and $CaCl_2$ mixture, for example,industrial copper and copper alloy are tested forcially, in which copper-nickel alloy, that is said to be good to anti stress-corrosion and cracking is tested most carefully. In Fig. 4, tested results with copper and copper alloy of several kind, and copper-nickel alloy changing nickel content are shown.
From these data, copper-nickel of low nickel content, naval brass and industrial copper are good for anti-corrosivity, although it has been known that stress corrosion cracking is occured at copper-nickel alloy of a certain high nickel content.

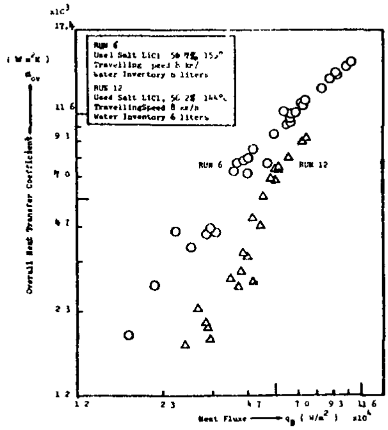


Fig. 3.Over-all Heat Transfer Coefficient

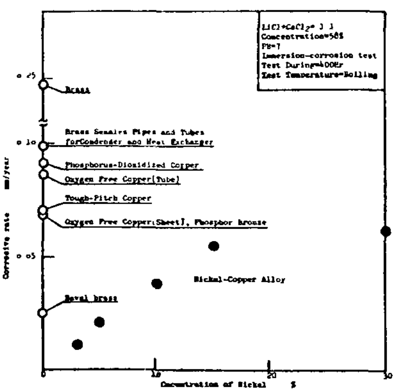


Fig. 4. Selection ofMaterial for CDE System

CONCLUSION

CDE engine and system are studied here with some successful experiments of simple CDE engine. By the results up to today, the theoretical and practical specific power of CDE engine per unit weight is thought to be nearly the same to those of conventional lead storage battery. By utilizing their high performance of energy storing capacity, and by developing favourable solutions and anti-corrosive materials of low expense. The CDE engine and system will have wide future promising application in the economical storage and conversion of all kinds of alternative energy fields.

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1. Isshiki, N.,Kamoshida, J., et al,. " Energy conversion and storage by CDE engine and system ", 12th IECEC, 779180, 1977.

2. Issiki, N.,Nikai, I., et al,. " Heat transfer of absorbing evaporator in CDE engine system ", 6th IHTC, 1978.

AN UPDATE IN THE "DEVELOPMENT OF ALTERNATE LIQUID FUELS"

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Alternate liquid fuels ALF^{TM} fuels have been developed, with essentially similar characteristics as commercial ASTM fuel oils (grades #2, 4 & 5), at a direct cost ranging from 17.5 to 27.9¢ per gallon depending upon selected feedstocks and blend ratios.

Since FY '77 approximately 19 million gallons of ALF^{TM} fuels have been produced, and consumed in the Central Steam Plant at Brookhaven National Laboratory. Conservatively this represents an initial saving of over $1,600,000 thru May 1979.

ALF^{TM} fuels are formulated by "selectively blending" feedstocks of recycled or previously used semi-miscible alcohols, mineral spirits, solvents and other combustible liquids with sub-standard but conventional fuel oils obtained from government surplus or purchased in the spot-market (e.g., Navy Special, Bunker "C", petroleum pipeline interfaces, #6 residual oil from tank and barge bottoms).

The inherent tendency for these feedstocks to separate from mix was resolved by improved processing system design and methodology that evolved from bench tests, laboratory analyses and trial firing of ALF^{TM} fuels in commercial and industrial boilers.

Some Advantages of Alternate Liquid Fuels

1. It is classified by the U.S. Department of Energy as a non-critical or preferred fuel.

2. It is a cost effective high yield BTU fuel that can be produced with readily available feedstocks utilizing standard hardware and processing equipment.

3. It has a low sulphur (.5%) and ash (.02%) content thereby minimizing fireside deposits, improving heat exchange efficiency and reducing particulate emissions.

4. Initial fuel analyses indicates that ALF^{TM} fuels should exhibit clean-burning characteristics. Field observation also indicates that the feedstock(s) in ALF^{TM} fuels may be functioning as a combustion catalyst, for the heavier hydro-carbon elements in this fuel, thus

resulting in a more complete burn at lower levels of excess air. Therefore, the potential for a notable increase of combustion and boiler operating efficiency appears evident.

5. ALF™ fuels can also be formulated as a low cost fuel for diesel engines and gas turbines by varying the blend ratios of the various feedstocks.

6. Under the "Energy Tax Act" (National Energy Act 1978), qualified users of ALF™ fuels would be eligible for an additional 10% (for a total of 20%) investment tax credit for;

   a. Purchase of equipment that use or produce alternate fuels (boilers, gas turbines, diesels, fuel handling and storage systems, etc.)

   b. Recycling apparatus and systems for processing waste (liquid or solid) fuels and other materials.

   c. Accelerated depreciation for combustors capable of conversion to synthetic fuels.

7. It provides a safe and environmentally acceptable method for the disposal of spent industrial (flammable) liquids.

8. Certified laboratory analyses indicate that the feedstocks, for ALF™ fuels, are free of all known carcinogens. In addition, toxic and hazardous substances, referenced by the United States Environmental Protection Administration, are essentially absent.

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TESTS	RESULTS
Gravity, API @ 60°F	30.6
Gravity, API @ 40°F	29.3
Vis. S.U. @ 100°F	43.0 sec.
Pour point, ASTM	30°F
Sulfur, ASTM	0.50%
Water & Sed.	0.3%
Water distillation	0.1%
B.T.U. per pound	19,496
" " gallon	141,716
Lbs/gal.	7.269
Flash point, COC	Below room temp.
Fire point, COC	Room temp.
Ash	0.02%
Lead	19 PPM

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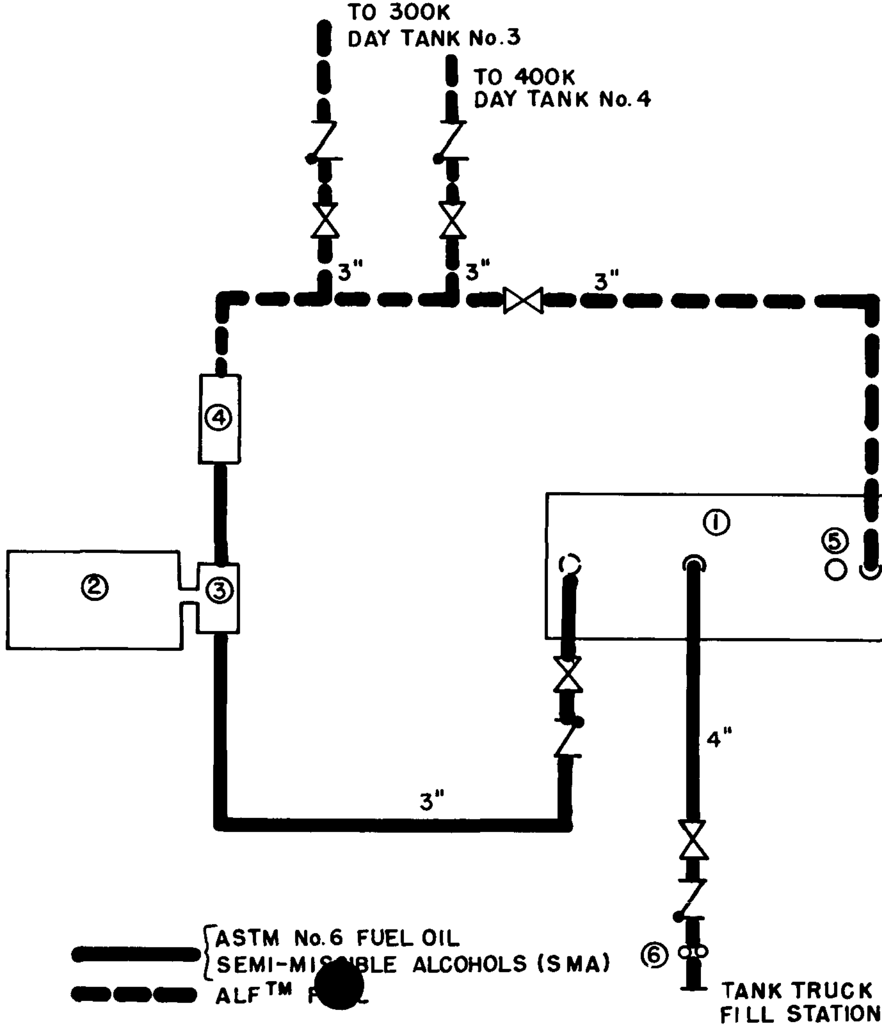

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DWG I

ALF™ FUEL MIXING PILOT PROCESSING SYSTEM

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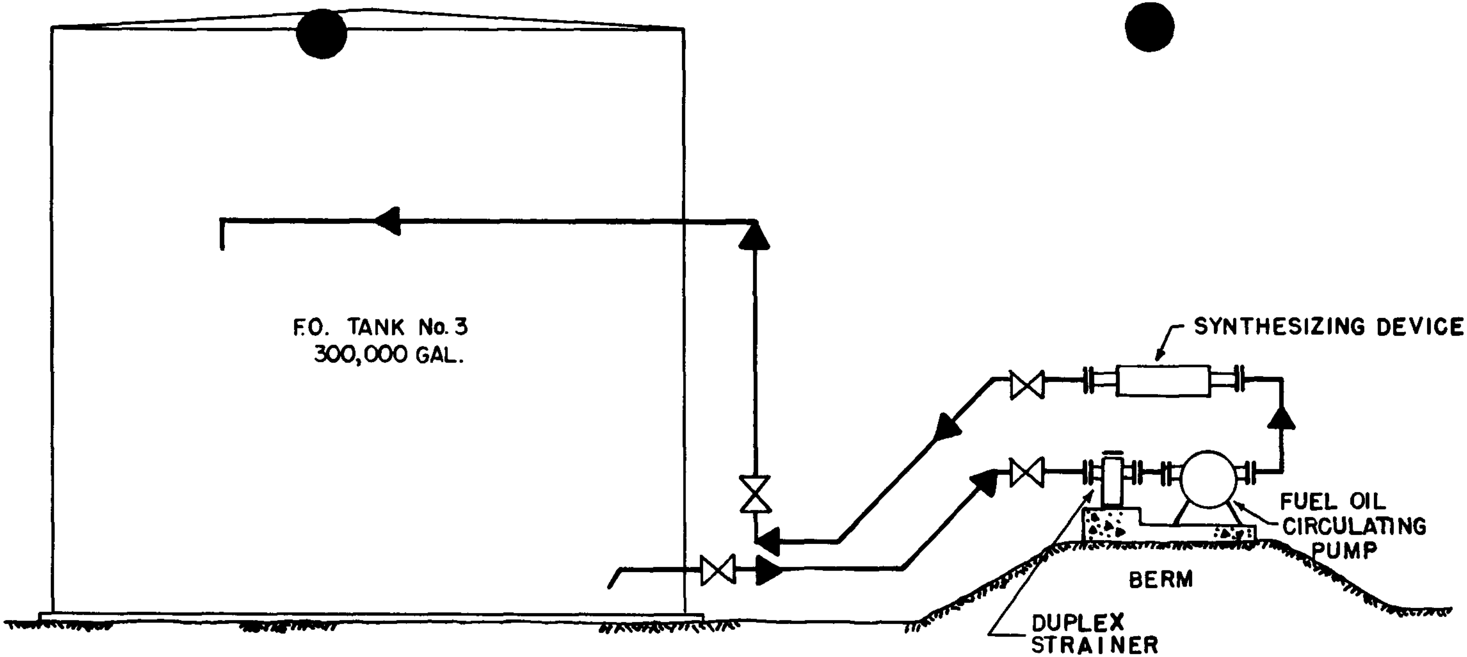

DWG II

ALF™ FUEL MIXING

SCALED - UP SYSTEM

BROOKHAVEN NATIONAL LABORATORY
PLANT ENGINEERING
UPTON, NEW YORK 9/78

The conversion of peat: recent developments in simultaneous dewatering and hydrogenolysis.

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Recent estimates of peat resources in North America have resulted in a spur of research directed towards its use as an energy source. The major problem associated with peat conversion is its dewatering prior to conversion. This requires unique mining and drying methods which are cumbersome, expensive and of low productivity. By combining hydraulic mining techniques together with hydrogenolysis of the slurry in the presence of carbon monoxide and hydrogen, peat can be converted into a bitumen-like organic material which separates readily from the aqueoues phase and which can be used either directly in combustion processes or as feedstock for the production of liquid fuels. In this presentation the conversion and liquid yields will be reviewed as a function of operating parameters: temperature, residence time, pressure, carbon monoxide to hydrogen ratio and catalysts added. Liquid yields (benzene solubles) reach values as high as 54% of the organic matter present in peat. The combined action of carbon monoxide and water is required for these relatively high yields. Also the presence of alkaline salts seems to influence favourably the conversion process. Material balances show that the hydrogenolysis reaction is a net hydrogen producer and consumes a significant fraction of carbon monoxide. Thus although the exit gas from the reactor can be recycled a carbon monoxide enriched make-up gas from a gasifier is required. Since this gas can be obtained from peat, the process becomes autonomous.

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FUTURE OF ALCOHOL FUELS PROGRAMS IN BRAZIL

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EXTENDED ABSTRACT

SUMMARY

An updated account of the Brazilian National Alcohol Program achievements both on production and utilization of ethanol fuels is presented. The recently proposed program on Methanol from wood (eucalyptus) is also considered and utilized as a basis for the establishment of possible scenarios for future Fuel Alcohols production and utilization in Brazil up to year 2000. Conclusions about the impact in the automotive industry, balance of payments and job creation are presented.

PRESENT ENERGY SITUATION

Brazilian total energy demand has grown at an annual rate around 7% over the last 10 years reaching 103 million tons of oil equivalent-TOE in 1977. The projected demand for the future requires new energy technologies to help reduce the heavy dependency on crude oil (42% of total energy demand) since 84% of it is imported with a severe impact on the Brazilian balance of payments.

Among the many non-conventional energy sources likely to be implemented in Brazil, the alcohol fuels alternative seems to have an important role to play in the energy system. This is due to the fact that alcohols do not present technical impediments as substitute for almost all oil derivatives in Brazil (excluding probably lubricants, asphalts, kerosene).

PRESENT STATUS OF ALCOHOL FUELS

As of August 1979, 232 new or expanded ethanol distilleries will add a new capacity of $4.3 \times 10^6 m^3$ of alcohol/year within 2-5 years. Those projects have been approved by the National Alcohol Commission-CNAl and will receive subsidized government financing through the National Alcohol Program - PROÁLCOOL.

About $1.39 \times 10^6 m^3$ of ethanol (hydrated plus anhydrous) was produced in the calendar year of 1977, 46% of which being distributed through blending centers to prepare 20% anhydrous ethanol - 80% gasoline blends. This corresponds to savings of about 5% of domestic gasoline demand in the same year. In 1978 about $2.36 \times 10^6 m^3$ of ethanol was produced, 64% of which added to gasoline corresponding to 11.0% of domestic gasoline demand. The balance was used as raw material for the chemical industry, cosmetics, pharmaceutics or exported.

Estimates for the current year (1979) indicate that 3.1 x 10^6 m^3 of ethanol will be produced in Brazil, i.e., a 31% increase over the previous year. A distribution system includes today about 50 blending centers all over the country, where the 20% ethanol - 80% gasoline blend is prepared. If the distilleries already approved by the National Alcohol Commission begin production as scheduled, about 4.0 x 10^6 m^3 of ethanol would be produced in 1980. The official target for 1985 is 10.7 x 10^6 m^3 of ethanol, which corresponds to roughly 70% of the gasoline market in 1978.

As of July 1979, 10 different straight ethanol (96% w/w) vehicle fleets with a total of 742 vehicles equipped with converted Otto engines are under test employing technology developed by CTA, the Brazilian Air Force Research Center. These fleets were performing commercial activities, with a cummulative mileage of 11 million miles, to demonstrate its technical - economic feasibility. In July 1979, the Brazilian subsidiary of FIAT begun production of straight ethanol vehicles (light Otto engines). Volkswagen, General Motors and Ford should begun production of straight ethanol vehicles in the second semester of 1979. As of September '79 about 2,500 vehicles were running on straight ethanol fuel. Public service stations begun selling hydrated ethanol fuel on May 5, 1979 in 5 different cities (Rio de Janeiro, São Paulo, Brasilia, Recife and Maceiõ) at a price of about US$ 1.00/gallon, whereas regular gasoline price has just been increased to about US$ 1.80/gallon (September 10, 1979). Official estimates indicate that 250,000 straight ethanol vehicles should be running by the end of 1980.

Methanol is being seriously considered by CESP - São Paulo State Energy Utility as an oil substitute. The program is based on 2,000 ton/day methanol plants using wood as raw material. Several experiments with methanol as fuel for Otto and Diesel engines and boilers are also being conducted in Brazil under CESP's support.

In addition, 2.6 x 10^6 methanol/month from natural gas were approved by the Government to be blended with ethanol and gasoline in the State of Bahia for automotive fuel purposes. The addition of methanol to ethanol was done at the methanol factory firstly at a ratio of 30% MeOU/70%EtOH and afterwards at 10/90%. The alcoholic blend was then added to gasoline at blending centers, at the proportion of 20% alcohols/80% gasoline by vol. This blending occurred from July 1978 to February 1979 and should cease as the chemical market for methanol develops in Brazil.

SCENARIOS

Alcohols and raw material availability, economical, political and social factors, and the consideration of other important alternative energy sources may considerably change the pattern in which alcohols as oil substitutes can be considered in the energy scenarios through the year 2000.

Hydro and nuclear power, domestic coal, solar thermal applications and other biomass fuels such as vegetal oils may as well have an important contribution. Therefore it is necessary to analyze the impacts of different scenarios for methanol and ethanol on the following: required investment/automobile manufacturing/straight alcohol vehicle fleets/ alcohol distribution/manpower requirements/oil imports/ecological impacts, among others.

The utilization of methanol and ethanol as fuels is considered for transportation (Otto and Diesel engines), for utilities and industrial sectors (gas turbine and boilers) in the Brazilian context. The energy demand scenarios also take into consideration factors such as: the gain in thermal efficiency due to high compression ratios possible with straight alcohol Otto engines (12:1), and other end-use efficiencies/ technical bounds for blends with oil derived fuels/upper and lower bounds for alternative fuels market penetration over the years/future strategic targets/modification of current transportation pattern heavily dependent on highway transportation/and different oil refining strategies.

Alternative scenarios of alcohol fuels utilization are developed employing a dinamic energy model which take into consideration the above mentioned factors.

MAIN CONCLUSIONS

. Production of straight ethanol vehicles may represent significant percentage of total domestic automotive production (15% to 100%) depending on the year and availability of alcohol fuels for the sector.

. Impact in the balance of payments is extremely favorable even if 100% of investments come from foreign sources.

. Job creation due to alcohol fuels programs is several orders of magnitude larger (100-1000:1) than for petroleum fuels at the present situation.

. Alcohols should substitute different petroleum fuels in order to achieve actual crude oil savings; alternatively, large modification of refining schemes should be adopted to meet, for instance, medium distillates demand avoiding excessive surpluses of light distillates.

THE COMMON SENSE APPROACH IN DEVELOPING FUEL ALCOHOLS

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EXTENDED ABSTRACT

Fermentation alcohols can be obtained from a very diverse series of primary materials - sugars, starches or cellulose from waste materials or energy crops. The production of the alcohol is a technology going back to the days man learned to make wine and whiskey. Also, going back to the 18'0's, Henry Ford realized the value of "power alcohol" for his automobiles. As a result of very self serving interests on the part of the petroleum industry, doubts were promulgated relating to whether the cultivation of energy crops makes sense in terms of energy yields and overall economics. The subject of alcohol fuels is diversified and dependent on specific climatic and economic environmental conditions. Nevertheless, certain generalities can be drawn when analizing the practicality of developing fuel alcohols.

This paper deals with the use of fermentation alcohol as an octane booster for inferior regular unleaded gasoline. At a time the oil companies in the United States have been told to decrease the quantities of lead and manganese compounds added to gasoline, the oil companies turned to the production of octane boosting additives via secondary processes at the refinery. These "reforming" processes require additional inputs of crude and therefore the crude and the cost of production allocations to the gasoline component are higher than for the other fractions produced at the refinery. In effect when substituting 10 percent gasoline with ethanol one does replace not only 10 percent petroleum products, but an additional 6 percent pf crude that would have otherwise been used up in producing the octane-enhancing reformates. The paper shows that when one does a complete analysis of the crude replacement value of ethanol one finds that one btu of ethanol is equivalent to 3.77 btu of crude. This analysis rejects therefore the oil industry backed proposition that when phasing in fermentation fuel-ethanol, one increases the dependence on crude.

Having considered the energy balances we turn our attention to ways how to link farm policy with energy policy. Special attention is given to United States farm policies that subsidize so called set-aside and land diversion programs where

a percentage of the land is left idle and the farmer is paid to decrease his output in order to support the price of the commodity. It is shown that these subsidies could suffice to establish an economically viable fuel alcohols industry in the United States. Some proposed U.S. legislation favoring fuel alcohols is described.

ALCOHOLS AS AUXILIARY FUELS FOR DIESEL ENGINES

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ABSTRACT

Alcohols are among the principal contenders as possible engine fuels. This investigation aims at studying the effect of alcohol substitution in diesel engines on their performance and exhaust emissions. Alcohol was carburated into the intake manifold of a single cylinder diesel engine and the ignition was achieved by injecting diesel fuel into the cylinder in the conventional manner. The engine was operated at different load conditions. The investigation indicated that alcohols, both methyl and ethyl, can substitute diesel fuel in large proportions for diesel engine operation, with attendent decrease in exhaust nitric oxide emissions. Such operation is possible with minor modifications to the engine system.

This investigation establishes that alcohols can be used in large proportions in open chamber diesel engines, both for normal running and power boost operation, with considerable reduction in exhaust pollutant emissions. Engines can be operated with alcohol carburation near full load conditions with no appreciable loss of thermal efficiency. With a reduction in cycle temperature level due to high latent heats of vaporization, alcohol carburation reduces the nitric oxide concentrations in engine exhaust considerably.

SESSION 6F

ECONOMICS AND POLICY V

ENERGY DECISION-MAKING UNDER UNCERTAINTY

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EXTENDED ABSTRACT

This paper addresses the various types of uncertainties which must be dealt with in developing viable electric power strategies. A successful strategy, in turn, depends on deciding which options, among a large number of potential research and development options, should be pursued with the limited resources available. As another way of saying this--we must decide on the R&D priorities which will properly support a strategy (or strategies) which can cut through an uncertain future.

What are the uncertainties? They can be briefly characterized as follows:

- Electric demand uncertainty (Demand growth is a complicated function of economic growth, the price of electricity and the prices of potential fuel substitutes for electricity, conservation penetration, and other factors--all of which are uncertain.)

- Electric supply uncertainty (Conventional electric supplies face uncertainties; such as, the future availability and price of oil, environmental limitations on the use of coal, and public acceptance of nuclear. Advanced methods face uncertainties also: estimating when a technology becomes commercial, how much electric production at such time, and the costs of power from the technology.)

- Regulatory/political uncertainty (Regulatory uncertainties relate to future changes by federal and state regulators on rate schedules for electricity/fuels and environmental standards, as examples. Political uncertainties relate to the fact that changes in federal and state administrations and legislatures often bring significant changes in energy policy.)

- "Event" uncertainty (Unpredictable events can occur, having significant impacts on an energy strategy. The 1973 oil embargo and dramatic oil price increases, the 1979 Iranian oil crisis, and the Three Mile Island nuclear accident are recent examples of such events.)

The breadth and diversity of these uncertainties are obviously considerable. How can we make tractable the problem of dealing with them? If we had unlimited resources which could be applied to the problem, the solution would be to simultaneously pursue multiple R&D paths on an accelerated basis. Clearly, we are not in such a fortunate position,

and we must in fact attempt to allocate limited resources to solving the problem. Unfortunately, there simply is no integrated approach as yet for doing so.

The setting of R&D priorities is really a combination of techniques involving decision analysis theory, past experience, judgment, and intuition. For example, EPRI is currently experimenting with several decision analysis approaches which attempt to model demand and supply uncertainty, including regulatory uncertainty to some extent. The objective is to quantitatively evaluate the benefits of alternate R&D paths. As another example, EPRI carries out an annual survey of R&D priorities. This evolving survey attempts to obtain quantitative and qualitative input from senior people, in both the public and private sectors, as to EPRI's R&D programs. The survey is being continually improved to better tap the experience, judgment, and intuition of these individuals.

We probably will never develop an "integrated model" which will show how R&D priorities should be established to provide an optimum path through our very uncertain energy future; however, we should be able to approach the problem with logic and consistency by using the methods mentioned above.

PERCEPTIONS OF RISK AND TIMING IN BREEDER REACTORS DEVELOPMENT DECISIONS

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Large scale deployment of fast breeder reactors has long been viewed as a potential source for essentially unlimited generation of electric energy. The recent slowdown of the electric demand growth rate and of the installed "conventional" Light Water Reactor capacity, have pushed back the target dates for the commercialization of this technology in most countries. The concerns with nuclear weapons proliferation due to misuse of the civilian nuclear fuel cycle have resulted in the indefinite deferral of breeder deployment plans in the United States, as compared with other industrial nations, which still favor the commercialization of the breeder on security of fuel supplies considerations. This paper argues that based on realistic introduction constraints only few of the highly industrial nations, with a large interconnected electric power grid could add breeders to their supply systems before the end of this century. In most other nations breeders construction should be preceded by the development of a large interconnected power system and by the operation of a significant number of LWRs which would justify the introduction of this advanced and highly centralized nuclear technology.

The role of the fast breeder reactor (FBR), in the few nations that will be able to install this power plant, will be dual. FBRs would represent a major source of electric capacity required as a hedge against future high demand growth. Breeders are also less sensitive to fuel price escalations which affect all other base load generating technologies. In that sense the high FBR capital cost penalty, will be recovered over the lifetime of the reactor as the alternative power capability will be a LWR, a coal or an oil fired power plant. The other role for the breeder is as a hedge against uncertainties in the nuclear fuel cycle. Viewed from a limited national perspective, the availability of uranium on the international market is somewhat restricted, and supply depends on a large set of safeguards and retransfer regulations. Availability of enrichment services, though adequate till the late 1980's represent another source of uncertainity at the front end of the nuclear fuel cycle.

Countries with a large nuclear capacity might then be willing to pay premium prices in order to insure the continuity of their uranium supplies. The premium for guaranteed nuclear fuel supplies, in the form of higher prices or financing of fuel cycle ventures, will change the relative economics of the breeder, as compared with the LWR. The effects of uranium price and of the probability of supply assurance on the economics of the FBR, are shown in Figure 1. Breeders might be viewed as a strategic option which will reduce the dependence on imported nuclear fuel and which will increase the capability of the national utilities to generate the required electric power.

It should be stressed that different countries are endowed to varying extents with nuclear or alternate energy resources, and have differing perceptions, regarding the need and the timing for breeders commercialization. The economic and social acceptability of the FBR are highly situation and time dependent, and thus no single inflexible policy could be applied to the issue of the international deployment of this power technology.

A generic rationale for a FBR research development and demonstration (R&D) program, which will provide an advanced low cost power plant, can be formulated by postulating two equal likelihood states of the world: One favorable to FBR introduction in terms of both the need and the technology availability and the other unfavorable. These states of the world will result in fast and slow FBR penetration rates into the electric capacity mix of the U.S. and in a total undiscounted difference in electricity generation costs of $320 billion dollars, beyond 2010. We could also specify two long term breeder RD&D programs: One leading to improved low cost technology and the other, at a reduced budget, leading to a high cost, low performance FBR plant. We further assume a budgetary increment of 10 billion dollars between the high and low cost development programs. The interactions of the two potential states of the world and two R&D programs lead to four possible outcomes listed in Table 1.

As seen in Table 1, the downside risk of unnecessarily accelerating the FBR development program is much smaller than the upside risk of not having the advanced technology available when required. Using Table 1 results, it is found that any probability greater than 3 percent that a high growth future evolves, would justify the breeder R&D expenditures in terms of reduced risk of high electricity costs.

This generic analysis could be applied as well to other high cost, high payoff energy technologies such as photovoltaics or coal liquids. The significant feature of this analysis is the robustness of the decision to proceed with accelerated FBR development over a large range of probabilities of possible futures. Due to the recent slowdown of elective load demand growth rates, there does exist a sufficient time period to develop and improve the institutional arrangements required to properly safeguard the breeder generation option, before large sale deployment of this technology occurs.

TABLE I

POTENTIAL LOSSES IN DIFFERENT FBR DEVELOPMENT STRATEGIES

	High growth future advanced FBR technology fast penetration (1)	Low growth future immature FBR technology slow penetration (1)
Accelerated R&D program	No loss	Loss of R&D program cost (10×10^9 \$)
Low level R&D program	Loss of difference in electricity costs (320×10^9 \$) (undiscounted)	No loss

Potential losses in accelerated R&D program

$$0.5 \times 0 + 0.5 \times 10 \times 10^9 = 5 \times 10^9 \text{ \$}$$

Potential losses in low level R&D program

$$0.5 \times 320 \times 10^9 + 0.5 \times 0 = 160 \times 10^9 \text{ \$}$$

(1) 50 percent likelihood specified for each possible state of the world.

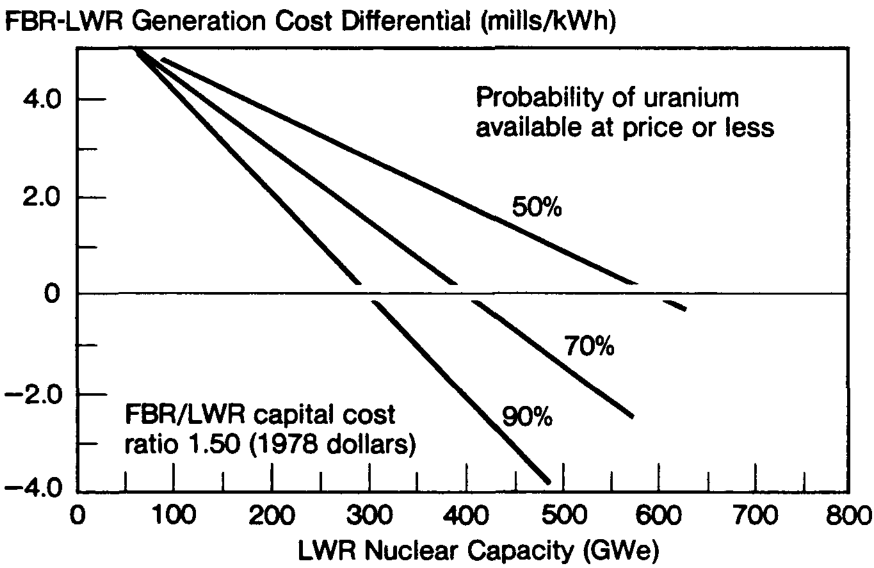

Fig. 1 - Perceived FBR-LWR Generation Cost Differential

A B S T R A C T

A Multi-Period Regional Network Model
of the Energy Sector

by

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An interractive multi-period energy planning model featuring the various forms of energy sources, distribution systems, technologies, own price-demand elasticities by product and by sector, as well as price leader pricing scenarios has been developed.

This is an equilibrium model that solves over a multi-peri planning horizon for equilibrium energy prices, demands and supplies, thereby maximizing consumer surplus at every period given the price leader's set price for oil - or any other reference commodity.

Tests performed with a multi-region problem over a long te planning horizon are discussed. These tests demonstrate the hi computational efficiency of this network modelling technique, thereby making it possible to use this model interactively. Tes esults with a 3 region world energy scenario are discussed.

SOLAR ENERGY FOR MULTI-UNIT RESIDENTIAL WATER HEATING: AN ECONOMIC ANALYSIS

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EXTENDED ABSTRACT

INTRODUCTION

Rapid adoption of solar energy conversion is an important component of comprehensive energy programs throughout the world. An intensive use of solar energy depends, however, not only on technical feasibility but also on (economic) users' cost. Many promising technological advances in the solar conversion field took place in the recent past and their economic advantages are still being tested. There is, however, a sub-field in solar energy conversion which may be viewed as both technically and economically proven, given today's fuel prices. This is the solar-to-thermal conversion through the use of collectors. The purpose of this paper is to present an economic analysis of solar systems for water heating for a multi-unit residential complex.

As noted, I concentrate on solar-to-thermal equipment for residential use where the technical system has already proven to be economically viable. Nevertheless, solar conversion alone is not sufficient to fullfil all household hot water requirements in most regions. Therefore, in most cases a combination of solar conversion and some other form of source energy is needed. The overall economic performance of the system thus depends not only on the cost of the solar equipment but also on the costs of the complementary source of energy. This study explores in detail the cost effectiveness of four combined solar systems. The basic methodology is that of standard cost accounting. The method is applied to a particular case study which serves to illustrate its use.

DESCRIPTION OF THE SYSTEM

The solar system design used for this analysis is based on the well known and relatively inexpensive flat plate collectors. The collectors are fixed in place on the roof of a building but still achieve a reasonable energy capture. Over a wide range of climatic conditions they can produce hot water at 70°c or more which meets the requirements for residential space and water heating. Thus, they fit well in a sizeable segment of the energy market. In the flat collector system the heat is transferred via a liquid heat - transfer medium to an insulated storage tank through a heat exchanger. The heat transfer liquid is returned to the collector in a closed loop and the process continues. Because solar energy does not supply all household needs of hot water, it is backed by an auxiliary heating system. When the water temperature from the storage tank is too low the flow is cut off by a solenoid valve and the auxiliary system is activated.

We consider only new residential construction in the following analysis. The building characteristics assumed, are that of a multi-residence building. Several size buildings (condominiums) are considered: 16 units, 24 units, 32 units and 40 units. In each case a unit is designed for a small family. The standard apartment size for this analysis is $70m^2$. The buildings are built with reinforced concrete, cement-brick walls and an asphalt flat roof. The particular site which is considered in the following illustration is located at 32° North with elevation of 200m above sea level.

THE COST ACCOUNTING APPROACH

Unlike some previous studies, which assumed solar system costs to be proportional to the surface area installed, this study uses strict cost accounting data as a basis for the analysis. The approach works as follows. First, detailed engineering designs for the system (for various sizes of apartment buildings) are collected. These are converted into material components and labor hours. Then market prices are used to "translate" the physical system into investment cost. The next stage involves the conversion of the various investment expenditures into annual flows. These annual flows are then added to the operating costs. Finally, the total cost data are used to make economic comparisons. In particular they are used to estimate the anticipated decrease in cost per unit of dwelling as the cummulative number of units in the building increases. In addition, the effects of household consumption are measured.

The purpose of this analysis is to measure the cost effectiveness of solar based water heating systems as a whole and not merely the solar component. Since the total system includes also the backup component, 4 different back-up possibilities are considered. The first backup is private electric boiler heated by a 1.5 KW heating element. The second auxiliary source is a large central electrical boiler located in the cellar. The third possibility is that of a central heating unit which uses heating oil. In the fourth backup system, the solar system is linked to a central heating gas system.

The illustration which follows pertains to a particular site in Israel. Since this is a specific example, the usual caveats apply. The cost figures depend on relative prices of source, energy, materials and labor costs. The results are reported in IL monetary units. However, since our purpose is to compare various backup systems, we are interested in relative magnitudes. Therefore, the figures may be viewed as a "numerative" or an index and thus they still possess a fairly wide applicability.

THE IMPACT OF THE LEVEL OF HOT WATER CONSUMPTION

As expected, the results (see Table 1) show that for each backup system total cost increases linearly with consumption. The rate of increase is different from one backup system to another. As households' annual consumption (measured in Kcal) increases the weight of the fixed cost component declines. Since some backup methods (e.g., gas) involve large initial investments -- which in our model translate into higher fixed annual costs -- their economic profitability (in terms of cost saving) increases markedly as hot water consumption increases. A comparison between a solar system with backup of a private electrical boiler and one backed by a common cellar type electric boiler provides a good example. In a 24 unit apartment building, at a hot water consumption rate of up to 7,500,000 Kcal per annum, a private boiler is more economical. Beyond that point, a common electrical boiler is superior from a cost saving standpoint.

TABLE 1

Annual Costs Per Unit (in IL) of a 70% Solar System: 24 Unit Building

Type of Backup / Ann. Cons. 10 Kcal	Priv. Elec. Boiler			Com. Elec. Boiler			Cent. Htg: Oil			Cent. Gas Sys.		
	FC	VC	TC	FC	VC	TC	FC	VC	TC	FC	VC	TC
6,000	792	1728	2520	862	1676	2538	1126	738	1864	955	1315	2270
7,500	792	2160	2952	862	2090	2952	1126	923	2049	955	1644	2599
9,000	792	2592	3384	862	2514	3376	1126	1107	2233	955	1973	2928
10,500	792	3024	3816	862	2923	3785	1126	1292	2418	955	2302	3257
12,000	792	3456	4248	862	3340	4202	1126	1476	2602	955	2631	3557
13,500	792	3888	4680	862	3756	4618	1126	1661	2787	955	2960	3915

COST BEHAVIOR AND BUILDING SIZE

The term building size as used in this study refers strictly to the number of units contained in a building where the size of a single apartment remains unchanged. Our results show that, in general, as the number of units in a building complex increases, the cost per unit declines. However, there are a few notable exceptions to this rule. In some cases there is an interaction effect between annual consumption patterns and building size which causes an increase in total cost per unit as building size increases.

OMER: A TECHNOECONOMIC ENERGY MODEL FOR ISRAEL

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EXTENDED ABSTRACT

This paper reports on the current modelling work of the Energy Planning and Policy Analysis Group in the Management Sciences Research Center of the Technion-Israel Institute of Technology. The purpose of the OMER (Optimization Models for Energy Resources) project is to develop a quantitative model for the description and better understanding of the comprehensive role of energy in the national economy of Israel. The model is currently used a) to explore the implications of short-range energy decisions and scenarios, and b) to provide a consistent framework for long-term energy strategies for the Ministry of Energy and Infrastructure. OMER is a modular, multiperiod linear programming model that describes, mainly in physical terms, the interactions within and across the sectors of the national economy and includes detailed energy production sectors. The first national energy model of this kind was developed at Stanford University by G.B. Dantzig and co-workers for the U.S.

As usual in this kind of modelling work, a large amount of data had to be collected from various sources and integrated by the modelling group. There is a close continuous interaction between data supplying sources (mainly industrial and governmental) and the modelling group. In many instances, the data necessary for the model had to be specially collected or measured in order to comply with the model formulation. On the other hand, the availability of data influenced the formulation of the model. The modelling group is also actively interacting with decision makers who are the ultimate users of the model. Energy and economic policy considerations of the decision makers have an important impact on the directions of the modelling effort. Such considerations may include national goals, possible scenarios and policy alternatives. In the following, the discussion will center around the modelling aspects of the project.

In its present form the model consists of the following five major portions: energy producing sectors, energy consuming sectors, domestic investment, foreign trade, and workforce.

The energy producing sectors are presently represented by two modules (submodels). The first module consists of the mainly technological description of oil and gas exploration, refining processes, and oil import activities. Presently about 99% of the oil consumed in Israel is imported and the proven oil and gas reserves of the country are negligible. Imported oil varies with respect to its source, and its chemical composition. The slate of refinery products that can be produced in the existing refineries depends on the latter property. On the other hand, the desired mix of products is determined by the demands of the consuming sectors. Thus the types of quantities of crudes and refinery products are endogenously determined by the model. The second module in the energy producing sectors describes the electricity production and distribution system. Presently all electricity generating facilities in the country are oil-fired. However, the first coal-fired power plants are already under construction and will be operative in the near future. In addition, the capacity expansion of the electricity production system modelled in OMER includes nuclear power plants and a hydroelectric project, possibly linked to pumped storage facilities. The output of the electricity module in OMER consists of base-load and peak-load high and low voltage electricity whose quantities are endogenously computed in the model. A third energy producing module, to be included in OMER at a later date, will consist of new energy producing technologies. Among those one can mention solar energy for uses other than the already widespread flatplate collector technology of domestic water-heating; utilization of peat and oil-shale deposits; coal gasification and liquefaction; and dual-purpose power generation and desalination plants.

The energy producing sectors supply energy products to the energy consuming sectors, consisting of the industrial sectors of the economy, personal consumption, and public services. The nonenergy industrial sectors are represented in the model by a Leontieff-type input-output coefficient matrix. At present the nonenergy industries are aggregated into 15 sectors. Personal consumption of goods and services is modelled on the basis of consumer survey data. These data are used to construct private consumption profiles as a function of income. The main feature of this procedure is that no fixed relative consumption of the various goods and services is assumed. In contrast to private consumption, a fixed proportion between the consumption of goods by the public sector is assumed in the model. The total public expenditure is either exogenously given or it is linked to the level of private consumption or some other economic indicator.

Domestic investment is the activity of replacing old industrial equipment and/or expanding the output capacities of the industrial sectors. In the multiperiod linear programming model these activities are among the ones that link one period to another. In each period, a portion of the industrial output is allocated to domestic investment in the energy and non-energy sectors, such that the new production facilities built are assumed to be available in a fraction of the current period, or in one of the next periods. The allocation of goods and services to capital formation is determined endogenously by the model so that some desired growth pattern for the economy is followed.

Foreign trade activities are an important part of OMER and are modelled in detail, such that the levels of import and export are endogenously determined. In the model there are two types of imports: Noncompetitive (essential) imports, that is, those goods for which there is no domestic counterpart and are needed for the economic activities of the sectors. Competitive (nonessential) imports, that is, goods and services which are, in principle, substitutable by domestically produced ones. The latter can be considered as supplementing domestic output in order to obtain a better balanced bill-of-goods for final uses. The level of total imports is limited by a trade balance constraint, to be described below. Exports are treated in the model analogously to competitive imports, that is, levels of exports are determined by the model, generally with no limits on the quantities that can be exported, because of the small share of Israel in international markets. Imports and exports are linked by a trade balance constraint, representing the requirement that in each period total imports (in monetary terms) cannot exceed total exports (also in monetary terms) by more than an exogenously given amount.

The input of labor to the economic activities is modelled in detail by five skill groups. For each energy producing and energy consuming sector workforce coefficients are computed, representing the man-hours required for a unit output. The total number of man-hours available is limited by an exogenously determined quantity in the first period which gradually changes over time, following a projected population growth pattern, a shift towards higher share of skilled workers, and increased productivity.

The model is operational and runs are routinely made with the active participation of decision makers to provide energy and economic projections and to compare alternative policy actions.

SESSION 7A

SOLAR POWER SYSTEMS

COMBINED SOLAR AND FOSSIL FUEL SYSTEMS FOR ELECTRIC POWER GENERATION

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EXTENDED ABSTRACT

The need for utilization of solar energy has been increasingly recognized in recent years. Different schemes of using solar energy for electric power generation were proposed and investigated. In general, these schemes had the solar energy as only power source to fuel the generating system. Because of these, some kinds of energy storage were required and therefore, the generating plant would become extremely expensive.

The use of solar energy to supplement fossil fuels is proposed in the paper. The combined solar and fossil fuel system is so designed that the solar energy will be utilized to a maximum extent at the time when the solar energy is available. The balance of energy requirement is met by burning fossil fuels such as coal, oil and natural gas. Since the solar energy is used as a supplementary fuel, the energy storage frequently needed for a solar system will not be required here.

The paper will present a feasibility study of combined solar and fossil fuel systems applied to the conventional electric power generating station. The system under consideration has major components as the conventional fossil-fuel power plant. In addition, it has a water heating system fueled by the solar energy. When the solar energy is available, a portion of feedwater heating is done by the solar heat. This would result in a decrease of steam extracted from the turbine, and thus, in an increase of turbine output. For nights and cloudy days, the solar heating is not in operation and the entire amount of feedwater is heated by passing through the conventional feedwater heater train. The concept of combined solar and fossil fuel system is simple and straightforward. It can be also applied to the combined-cycle power plant or the cogeneration plant where the electric power and process heat are simultaneously produced.

Fig. (1) indicates a typical fossil-fuel power plant with seven feedwater heaters. In the operation without solar heating the net turbine

output is approximately 725,895 KW. When the first four heaters (counted from the condenser side) are disconnected and the feedwater heating is done by a solar heating, the turbine net output will increase by 3.98 percent. In other words the net increase due to the solar heating is 28,920 KW. For this case the solar electric generation efficiency is around 14 percent. However, it must be pointed out that this generation efficiency varies from one system arrangement to another. It would increase as the maximum temperature of hot water from the solar system increases. Based on the average plant heat rate 9000 Btu/KWhr, the fuel saving due to the solar heating is approximately equal to 570,000 MBtu per year.

To determine the acceptability of the combined solar and fossil fuel system, the break-even cost has been determined in this investigation. It was found that it varies with the price of electric power, annual fixed charge rate and the availability of sunlights at the plant site.

In summary, the proposed system presents no new demand on technology development. It may also have some economic advantages over the previous solar systems where the solar energy is used as a primary fuel. Therefore, the combined solar and fossil fuel systems should deserve more serious attentions from the energy industry.

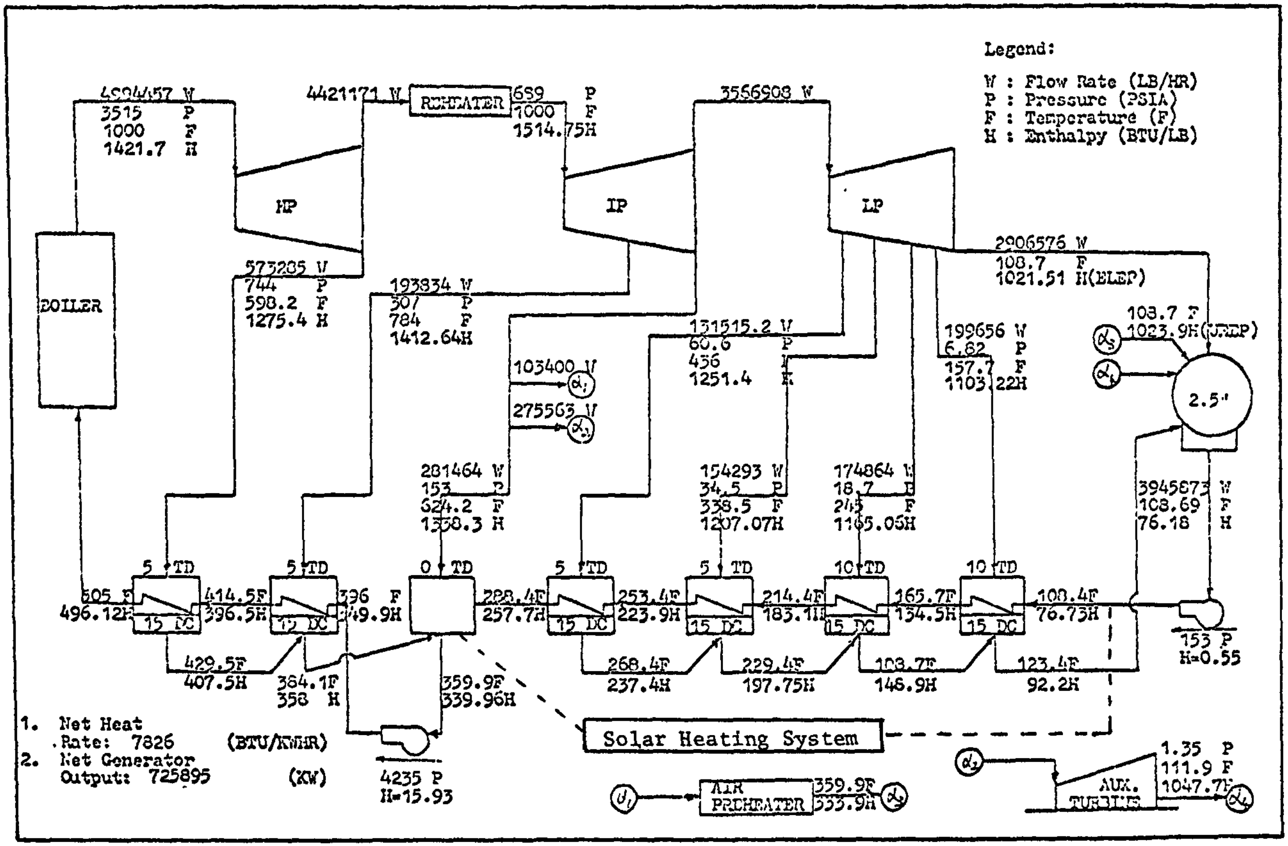

Fig. 1. Heat Balance Diagram of a Conventional Power Plant

SOLAR POWER GENERATION BY GROUND THERMAL ENERGY CONVERSION

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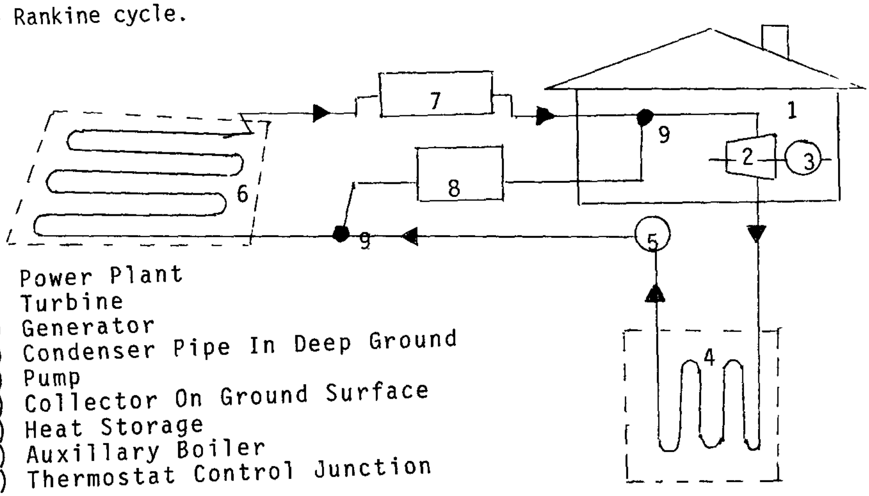
EXTENDED ABSTRACT

It is known that the earth temperature beneath certain depth in the ground is generally kept at constant due to thermal insulation of the ground, while on the surface the temperature varies from high at summer to low at winter. The variation of the ground thermal gradient can be used to drive a Rankine cycle for power generation. This paper describes the design of a power plant by means of the ground thermal energy conversion (GTEC).

The GTEC system basically consists of a ground solar collector, a heat storage, a low pressure turbine, a generator, a condenser loop, and a liquid pump. Loops of fluid-carrying pipes buried slightly beneath the ground surface are used to collect the solar radiation

which strikes the ground. The pressurized fluid flowing in the pipes absorbs the heat from the surface layer and becomes superheated. It is sent to turbine to generate power. After expansion in the turbine, the fluid exhausts to a loop of condenser pipes that is installed at some depth under the ground to dissipate heat. Using the ground as heat sink replaces the cooling water which is scarce in the arid zone. The cooled fluid is finally pumped back to the collector to complete the Rankine cycle.



1) Power Plant
2) Turbine
3) Generator
4) Condenser Pipe In Deep Ground
5) Pump
6) Collector On Ground Surface
7) Heat Storage
8) Auxillary Boiler
9) Thermostat Control Junction

FIGURE 1: A Sketch of the GTEC System

The system as described is shown in Figure 1. The ground heat storage included next to the ground solar collector is intended to store the solar heat for an extended period. The storage unit consists simply of an insulated concrete vessel that serves to store heat and to reduce heat losses. An auxillary boiler supplemented by a natural gas burner, though not needed, is included to ensure a continuous power plant operation.

In colder climate, the GTEC system can be made to operate in reverse fashion simply by changing the turbine to a pump and vice versa. In this case, the loop under the ground will act as a heat collector while the ground surface becomes a heat sink. It must be noted here that the GTEC system operating in this manner is not the same as that of geothermal energy conversion. The latter depends on the availability of superheated steam in the ground and consequently suitable sites are rather limited.

In Saudi Arabia, at mid-day, over a kilowatt of energy falls on every sunlit square meter of land. This energy can be easily collected by the simple means described above. Using transparent plexiglass sheets to cover the ground surface, the temperature under the cover can reach 75°C easily in summer. The ground temperature is about 25°C at a depth of 10 meters. The two temperature limits give a Carnot engine efficiency of 14.37%. With Freon-12 as the working fluid, a Rankine cycle efficiency of 8% could be obtained. During the winter, the collector temperature is lower. The system efficiency, however, can be improved by adopting high temperature solar collectors at a cost.

The GTEC system design is simple but versatile. The cost and skill requirements for construction, maintenance, and possible expansion can all be low in comparison with other types of solar energy power generation systems. In particular, GTEC has many advantages in terms of cost, location, safety and complexity over the ocean thermal energy conversion system. The GTEC system is more applicable to developing countries.

SOLAR ENERGY POWER GENERATORS WITH ADVANCED THERMIONIC CONVERTERS FOR SPACE CRAFT APPLICATIONS

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EXTENDED ABSTRACT

The solar energy exploitation in the space could be 6 to 15 times higher than on the earth. With this fact in mind, the total energy payback time of a spatial solar energy power generator (SEPG) is calculated in the range of 1,5 to 3 years and the energy payback for the transportation to a geosynchronous orbit is given as 4 to 6 months, whereas the total energy payback period for a terrestrial SEPG is estimated to be about 15 years [1]. This conclusion favours solar energy electricity production in a space power plant significantly.

On the other hand parabolic Fresnel mirrors as solar energy concentrator may reach concentration ratios up to 10^4 and temperatures up to $4000^\circ C$ [2]. Optimal operating temperatures for ordinary thermionic converters range from 1800 K to 2100 K [3-5] and for advanced hybrid thermionic converters with an auxiliary emitter from 1100 K to 1600 K [6]. Hence good chances can be granted to thermionic conversion of the solar energy in space craft applications.

The study presents (1) a 50 kW_{el} SEPG on a geostationary orbit for direct tv-broadcasting and (2) a 10 GW_{el} space power plant with their basic engineering outlines using an advanced thermionic converter proposal.

A preliminary study with advanced converters [7] has indicated a drop of approx. 50% in mass-to-power ratio on the earth orbit, compared with SEPGs containing ordinary thermionic converters [8-10]. Lower operating temperatures and greater electrode spacing (1,3 mm instead of 0,2-0,3 mm) of the advanced converters will also increase their lifetime significantly, compared with ordinary thermionic converters.

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The technology of the nuclear thermionic conversion for space application is rather progressed [11-17]. The presented SEPG reveals several advantages regarding the technology and lifetime. However, the main advantage of thermionic reactors remains their extremely compact construction, suitable for space transportation. The final assembly of any SEPG has to be carried out in a space orbit due to large collector surfaces, which is their essential disadvantage. Hence system studies dealing with this problem are going on [18].

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SOLAR THERMIONIC POWER PLANT (II)

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EXTENDED ABSTRACT

INTRODUCTION

A development program is now initiated in the university of Riyadh as an effort to commercialize a solar thermionic power plant (STEPP). The geometric configuration of the system is based on the central thermal receiver tower concept. By this concept high temperature large scale solar energy conversion became technically feasible.

Our research program is direct into two parts. As a first stage, a laboratory investigation of the design features of the thermionic diode and receiver cavity are carried out. In these experiments some of the problems existing in the construction of a specular reflecting surfaces was also considered. On the second part a series of studies are devoted to optimize the geometric configuration of the system to achieve an average concentration ratio more than 1600. Calculation was done for plant in a size of 150 kilowatts electric output as an experimental model for a one megawatt pilot plant.

An additional study which is not completed yet is concerned with the practical problems of building the thermionic diode converter into the solar electric power plant (SEPP), we have only some preliminary results.

SYSTEM DESCRIPTION AND CONCEPT

The solar thermoionic electric power consists of three major elements or sub-systems. A simple laboratory model for each element was constructed and tested. These element are:

1. Thermionic Diode Generator (TDG). The TDG has been constructed in the form of two cylindrical tubes. The outer surface of the cathode is heated by hot air supplied from a cavity receiver heated by a parabolic mirror concentrator. The anode is a cylinder with extended surface area coaxial with the cathode.

2. Central Thermal Receiver (CTR). A cylindrical cavity receiver was used to supply a hot air flow for heating up the cathode. The cavity effective absorbitivity (emissivity) were investigated for different cavity shapes, material and tube system carrying the heated air flow.

3. Solar Collectors (Reflectors). On this calculation the proposed system configuration was considered as square field trimmed at its outer boundary. In order to improve the utilization of the mirrors surfaces and to allow for smaller ratio between the reflector spacing and tower hight, the field was arranged in the form of south facing slope. The heliostates consists of a flat square mirrors of 1.32 m^2 area arranged on slightly bent frame to avoid enlargement of the solar image produced at the receiver.

SYSTEM OPTIMIZATION

In this proposed system the optical concentration must be sufficiently high that a temperature over 1200°C at the TDG cathode can be reached with minimum loss due to radiation or convection. A computer program was developed for the choice of the optimum STEPP scheme including assignement of the linear dimensions of the receiver and the size of the radiation receiving area.

The average solar thermal energy to the receiver was determined for Riyadh territory in the Kingdom of Saudi Arabia. The latitude of the site used in the calculation is 24° 38' N and the longitude is 48° 47' E. Isolines for mirrors of equal surface utilization were drawn at 8 different hour angles during the day; using the data for four typical days representing the four seasons. The total power from each heliostat which is observed by the receiver is then obtained, and the operating period of the TDG.

RESULTS AND CONCLUSIONS

The present study has shown the possibility of optimization of the geometric configuration of the CTR concept for a very high concentration ratio ($>$ 1600). It has been also show that gases could be used as a heat transfer fluid between the cavity receiver and the principle generators. A nearly cylindrical cavity with a depth to width ratio of about 1.4 and suitable material and coating can be heated homogeneously with only few percent loss. The test model constructed has promissed a conversion efficiency of about 30 percent. At this value the cost per unit power output from the STEPP is expected to be 8 percent than that from the SEPP.

SESSION 7B

NATIONAL GOALS FOR SOLAR ENERGY: ECONOMIC AND SOCIAL IMPLICATIONS

Reye

RESIDENTIAL PASSIVE SOLAR SYSTEMS:
REGIONAL SENSITIVITY TO SYSTEM PERFORMANCE,
COSTS, AND ALTERNATIVE PRICES

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EXTENDED ABSTRACT

Major research efforts have been undertaken to determine the economic and engineering performance of various residential solar systems. However, it is very important to develop consistant methodologies in order to evaluate the relative cost competitiveness of alternative passive solar systems. Various studies have indicated the desirability of passive designs from both an economic and operational standpoint, but many engineering, design, and economic parameters must be controlled to enable consistent comparisons.

Two passive space heating configurations are analyzed. These are a masonry thermal storage wall (Trombe) and a direct gain system--both with and without night insulation. Three standard home designs for each of the two passive systems are being used throughout the analysis to allow inter-regional comparisons. Moreover a "tract" concept and common building materials were assumed for each home design. The economic performance of these two systems is evaluated on a regional basis (223 locations) throughout the United States. For each of the three conventional energy types are considered (electricity, natural gas, and heating oil), sensitivity analysis is conducted to determine the impact of alternative fuel price escalation rates, solar costs, and consumer financial requirements upon the sizing and feasibility of the two solar systems.

Cost goals for solar system prices are established under alternative sets of future fuel prices and probable economic conditions. These cost goals define maximum allowable solar add-on expenditures for each location against likely conventional space heating fuels and their associated prices. Differences among cost goal targets are evaluated with respect to prices.

Alternatively, we examine future fuel price requirements (given solar feasibility) under allowable add-on cost expenditures for each of the three home designs. These add-on expenditures are established as a maximum percentage of average new home costs on a regional basis. Future fuel price requirements are defined as those energy costs which must be realized for the allowable, add-on solar costs to be achieved under competitive conditions. The escalation rates needed to bring present energy costs to the established minimum levels are regionally determined for each home design. These regionally determined escalation rates are then compared to published projections.

Dup

A PRELIMINARY ASSESSMENT OF SOLAR ENHANCED OIL RECOVERY

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EXTENDED ABSTRACT

Enhanced Oil Recovery (EOR) by steam injection is becoming an important means of extending U.S. reserves, accounting for 3% of U.S. production in 1977, or about $500 million per year. As crude prices rise, the economic feasibility of replacing the fuel burning steam generation system with a concentrating solar energy system is emerging as an interesting possibility. A preliminary systems study intended to assess the potential of Solar Enhanced Oil Recovery (SEOR) has been completed at Sandia Laboratories, Albuquerque. There are several qualitative reasons why steam EOR may be well suited to solar energy: 1) Sufficient land for the solar power requirements appears to be available, 2) it is possible that no thermal storage or backup system is required, 3) most of the steam EOR potential is in California, where insolation is high and tolerance of air pollution prohibitively low, 4) the energy form is thermal, at temperatures generally less than 600°F, where most concentrating collector systems can operate relatively effectively

These favorable qualitative features are reflected in the results of a cost model developed for comparing conventional and solar EOR. Included in the analysis are tax effects, O&M costs, salvage values, differential oil price escalation, inflation and discount effects. The reference system for this preliminary study is a field of parabolic troughs, without storage, generating 70% quality steam at 465°F at an average rate of 1.5 MW_t per injector (about 350 bbl of steam per day). At a cost of $200/$m^2$, such a system would require an initial investment of $2.5 million per injector, a reflection of the materials intensiveness which is typical of solar applications. The economics of SEOR is such that when the crude price exceeds a certain value (the breakeven price), then solar is the better investment.

Details of the assumptions made and nominal parameters chosen will be discussed, but the following are typical results. With a 12% discount rate and a solar energy steam system

which costs \$200/m^2 installed, and with 80% loan financing, the breakeven heavy crude price is \$11/bbl. At \$300/m^2 (more typical of present day costs) the breakeven price is \$17/bbl. If project financing is not available, the corresponding prices for equity financing are \$24/bbl and \$37/bbl, respectively.

Critical areas of uncertainty in the cost model inputs are oil price escalation rate, future collector costs, O&M requirements, and the availability of credit. Sensitivity analysis can be used to determine the variation of the breakeven crude price with individual changes in each parameter, and Monte Carlo analysis gives information about the distribution of results when all parameters are varied simultaneously and randomly.

An important system design consideration is how to handle the intermittency of the solar energy input. One possibility is to inject steam intermittently, but increased "sanding" in the well casing may eliminate this option. Other options which will be discussed are thermal storage, fuel-burning backup, low level steam injection for pressure maintenance, or some combination of these strategies.

The Department of Energy is attempting to stimulate joint projects involving the oil and solar industries through a recently issued Program Opportunity Notice for SEOR. The status of that program will be discussed briefly.

ENERGY ACCOUNTING FOR SOLAR AND ALTERNATIVE ENERGY SOURCES

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EXTENDED ABSTRACT

Energy in commercial forms is an intermediate good; that is, commercial forms of energy such as electricity or fossil fuels are consumed by machines to provide services to people. Yet when energy data are collected and displayed according to present reporting and accounting practices, little can be inferred about the actual services energy provides. Although studies of many of the end uses of energy have been undertaken, comprehensive end-use data are not collected periodically and reported in a consistent, illuminating manner. Rather, consumption of the various commercial forms of energy is often reported and displayed according to consumer type: such as residential, commercial, industrial, and various subdivisions of these major categories. The major thesis of this paper is that the actual services provided to end users should be a basic measure of energy use accounting.

Several inadequacies in present energy accounting practices have become apparent. First, many solar technologies provide energy services (such as space heating or water heating) directly from solar energy flux sources without the use of commercial forms of energy. Large-scale use of these technologies would be reflected in present energy accounts as a decrease in consumption of electricity or fossil fuels rather than as use of alternative means to provide basic services. Consider an example. In 1972 in the United States, approximately 13.9 EJ* of fossil fuels were burned by end users to provide space heat and hot water. Suppose that comparable heating service had been provided by technologies that directly utilize solar radiation. Using present accounting practices, U.S. energy consumption in that year would have been reported as 61.9 EJ rather than 75.8 EJ. Yet the same service would have been

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* One exajoule (EJ) is 10^{18} joules or 0.9478 x 10^{15} Btu (i.e., approximately 5 percent less than 1 quadrillion Btu).

provided to end users and the large scale use of solar energy for provision of this heat would not have been systematically counted. In fact, the use of solar energy could not have been distinguished - in the accounts - from reduction in demand for commercial forms of energy due to improvements in efficiency of end-use devices or to voluntary cut-backs in energy use.

A second shortcoming of most U.S. accounting practices is that fuels other than fossil and nuclear fuels are not counted explicitly. Yet, in 1972 nearly 3 percent of the fuels consumed at the point of end use was in the form of wood and its derivatives. With increased research emphasis on fuels from biomass and hydrogen fuel, this omission could considerably understate end-use consumption. Finally, hydroelectricity is presently converted to a "fuel equivalent" using a heat rate representative of fossil-fueled electric power plants. This convention emphasizes the amount of fossil fuel that would have been required to produce the same amount of electricity. The continuation of this practice and its extension to other solar technologies such as photovoltaic cells could considerable distort understanding of the actual energy sources utilized in a particular year and is inappropriate to an economy not based on fossil fuels.

These shortcomings in energy data collection and display are perhaps of little consequence in an economy like that of today in which most end-use services are provided via fossil fuels and electricity. However, the emergence of a wide variety of alternative technologies that might be used to provide these same services suggests that present accounting practices be reexamined and a more appropriate system devised. This paper proposes an energy accounting framework based upon the actual service provided to end users.

An energy service is defined as the service actually provided to ultimate consumers by their own use of energy measured, for example, in units of work or of heat at various temperatures per unit time. Fifteen categories of energy service are listed in Table 1. The proposed energy accounting framework consists of two matrices -- an *energy service matrix* and an *energy carrier matrix*. The *energy service matrix* displays quantities of energy services provided in various ways as well as quantities of energy carriers (electricity, fuels, or sensible heat) used to provide these energy services. The *energy carrier matrix* displays quantities of energy carriers used to produce and distribute energy carriers themselves to ultimate consumers. Table 1 is taken from an *energy service matrix* for 1972 and summarizes the measures of energy services and the quantities of services provided in that year.

This paper illustrates the proposed matrix accounting framework with 1972 energy data for the United States. Based on these data, several observations are made relative to long-range solar energy research and development policy.

TABLE 1

SUMMARY OF ENERGY SERVICES PROVIDED IN THE UNITED STATES IN 1972

Energy Service	Measure of Energy Service	Quantity of Service Provided
A. General Energy Services		
1. Space heating	Heat provided to rooms	7.78 EJ
2. Water heating	Heat provided to water	1.00 EJ
3. Space cooling	Heat removed from rooms	1.90 EJ
4. Refrigeration	Electricity consumer	182 TWh*
5. Cooking	Heat provided to cookware	0.10 EJ
6. Drying	Heat provided to drying spaces	0.16 EJ
7 Lighting	Electricity consumed	246 TWh
8. Electronic services	Electricity consumed	92 TWh
9. Appliance services	Electricity consumed	63 TWh
B. Industrial Process Energy Services		
10. Process heat	Heat provided to manufacturing processes	9.57 EJ
	via hot water < 100° C	0.56 EJ
	via steam	
	100-200° C	1.71 EJ
	200-350° C	0.64 EJ
	direct heat or via heated gas	
	< 100° C	0.62 EJ
	100-200° C	1 29 EJ
	200-350° C	0.50 EJ
	350-550° C	0.40 EJ
	550-1000° C	0.56 EJ
	> 1000° C	3.31 EJ
11. Mechanical Drive	Electricity consumed	295 TWh
12. Electro Processes	Electricity consumer	190 TWh
C Mobile Equipment Services		
13. Mobile machinery and service vehicles	Equipment-kilometers traveled	180×10^9 equipment-kilometers
14 Passenger transport	Passenger-kilometers traveled	4075×10^9 passenger-kilometers
Freight transport	Metric ton-kilometers hauled	3416×10^9 metric ton-kilometers
D Feedstock		
15. Feedstock	Heat equivalent of quantity consumed	7.68 EJ

* One terawatthour (Twh) is 10^9 kilowatthours.

ASSESSMENT OF FINANCIAL INCENTIVES IN COMMERCIALIZATION OF SOLAR TECHNOLOGIES

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1.0 INTRODUCTION

This background paper identifies and discusses potential financial barriers and incentives for renewable energy system commercialization. The paper concludes that there are six major financial barriers impeding commercial use of renewable energy systems. They are:

- Cost competitiveness with conventional technologies over the life of the system
- Manufacturer uncertainty of market demand
- Lack of operating experience with renewable systems
- Risk exposure associated with new untried technologies
- Capacity value decreases as market penetration increases
- Uncertainties concerning availability of Government support once a project is initiated.

In response to these barriers, there are several categories of incentives that can be employed to reduce these uncertainties and stimulate private investment. The incentive mechanisms include (1) grants, (2) subsidies, (3) tax incentives, (4) loan guarantees, (5) low-interest loans, and (6) guaranteed energy prices. There are also several innovative incentives such as fuel displacement credits and environmental offset credits which take advantage of the beneficial aspects of solar which can be defined within these incentives categories. Many of the incentive mechanisms already exist although there are no precedents for their use in renewable systems planning. Not all incentives are applicable to every potential purchaser of a renewable system. The private sector has the widest array of incentives available. Lastly, prior to establishing a series of incentive mechanisms for renewable energy systems we should take a hard look at our experience with past programs to ensure that we don't make the same mistakes. In summary, the incentives programs should relate to special assistance, be restricted to a target group, be intentional, make efficient use of fiscal resources, and be designed to phase out after the intended objective is achieved.

2.0 DESIRABLE FEATURES OF A FINANCIAL INCENTIVE PROGRAM FOR RENEWABLE ENERGY SYSTEMS

Using present U.S. subsidy mechanisms as a base, general guidelines for the implementation of an incentive program for renewable energy systems commercialization can be developed.

Certain general features regarding incentives programs should be noted: (1) they relate to special assistance or advantage, not general assistance; (2) they are restircted to a group, which may be a whole industry but not a single company; (3) they are intentional; and (4) they make efficient use of fiscal resources.

Desirable features to embody in an incentives program are as follows.

2.1 Beneficiary Identification The group to benefit should be clearly identified. This is important in the selection of an incentive or group of incentives to accomplish a specific purpose.

2.2 Determination of Need This is necessary in order to decide how much of an incentive is needed and for what period of time. Oversubsidization will waste money needed for other purposes.

2.3 Appropriateness of the Mechanism An inherent problem in any incentive program is that the beneficiary may relax his competitive efforts. The incentive may actually inhibit the efficiency with which commercialization occurs.

2.4 Flexibility In order to deal with the nature of an evolving industry, the incentive should be structured for easy and prompt adjustments if policy goals are to be reached with economy and efficiency. A self-adjusting mechanism reacting to market conditions can aid in offsetting many of the problems resulting from the lack of precision in long-range forecasts of future capacity, demands, and costs.

2.5 Benefit Versus Costs The importance of tradeoffs between costs and goals should also be recognized. It is important to measure the benefit received against the cost of the incentive at a more detailed level than heretofore accomplished. Accurate measures of costs and benefits are difficult to develop. They are, however, necessary in determining the value of each alternative incentives program.

SESSION 7C

HYDRO AND TIDAL POWER

ASSESSMENT OF HIGH-HEAD TURBOMACHINERY FOR UNDERGROUND PUMPED HYDROELECTRIC STORAGE PLANTS

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EXTENDED ABSTRACT

Underground pumped hydroelectric storage (UPHS) is a promising technology for utility peak-load generation. It is similar to surface pumped hydroelectric storage except that the lower water storage reservoir is located underground. At present, there are two UPHS configurations being considered--a one-drop and a two-drop scheme. In the one-drop scheme, there is only one underground reservoir below which is a powerhouse containing the turbomachinery. In the two-drop scheme, a smaller intermediate reservoir is located approximately midway between the upper and lower reservoir, and a powerhouse is associated with each reservoir. The intermediate reservoir allows the two plants to operate in series without synchronization of the turbomachinery and also permits the use of lower-head machinery than is needed for the same overall head as the single-drop scheme.

The power output of a hydraulic turbine is directly proportional to the volumetric flow rate and the head. In order to decrease the cost of the underground construction, which represents a major portion of the total cost of a UPHS plant, for a given power output, the reservoir volume must be decreased and the head increased. These economics provide the incentive for high-head turbomachinery development. Recent studies conducted for Argonne National Laboratory have indicated the technical and economic feasibility of single-stage, reversible, Francis-type pump turbines for operating heads as high as 1000 m. Similar studies have demonstrated feasibility of two-stage, gated pump turbines for operating heads up to 1500 m. The results of these studies represent a considerable extension to the current technology of reversible pump turbines.

In this paper, the engineering cost of integrating this advanced turbomachinery with a UPHS plant are discussed. Equipment used includes single- and two-stage reversible pump turbines for operating heads from 500 to 1500 m. The effects of machinery costs, operating heads, plant configurations and sizes have been taken into account. The results indicate that the use of advanced machinery is economically attractive and that the minimum UPHS plant costs occur at heads beyond that of plants equipped with "conventional" machinery. For heads at or below 1000 m, single-stage, reversible pump turbines appear to be a logical choice. For heads above 1000 m, the present work indicates that two-stage, reversible pump turbines represent an economically attractive option. A significant cost reduction results when a plant with two-stage reversible units is compared with two-drop configuration plants or plants equipped with tandem units. However, this cost reduction may be diminished when differences in pump turbine efficiencies are considered.

Because of the long plant and machinery lifetime, small differences in performance can result in nonnegligible cost penalties or benefits. It is shown that pump-turbine efficiencies and the so-called charge-discharge ratio are very important design parameters for UPHS applications. The interactive effects of these parameters have been analysed. Increasing the charge-discharge ratio will reduce the relative storage cost. However, this increase in charge-discharge ratio is accompanied by greater balance-of-plant costs and cost penalties resulting from possible reduction in turbomachinery efficiency. The cost benefit will depend on the amount of generation capacity require[illegible] For large enough generation times, the cost savings from reduction in sto[illegible] costs will outweigh the other associated cost increases. In these cases some sacrifices in efficiency from increasing the charge-discharge ratio may be acceptable. This result illustrates that evaluation of both capital cost and performance are essential in making a judicious choice of turbomachinery for UPHS application. Maximizing operating efficiency is only one among several important aspects in pump-turbine selection considerations.

KOREA TIDAL POWER AND BEYOND

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EXTENDED ABSTRACT

INTRODUCTION AND SYNOPSIS

The next major tidal power plant to be built will very likely be on the Republic of Korea's west coast, close to its capital, Seoul.

During 1978, a prefeasibility study was carried out by the Korea Ocean Research and Development Institute (KORDI) with the assistance of The Shawinigan Engineering Company Limited (Shawinigan) of Montreal, Canada.

The objectives of the study were:

1. To evaluate the tidal power potential on Korea's west coast and to determine the priority of sites;

2. To recommend a site for a detailed feasibility study.

The paper describes how these two objectives were achieved and summarizes the conclusions of the study. The paper then proceeds to project likely further developments in tidal power plant technology.

THE STUDY AREA

The highest tides in South Korea are found along the north west coast between latitudes 36° and 38° north. The coastline in this region is very irregular with numerous bays and inlets of varying sizes. The number of possible sites for tidal power barrages to create reservoirs is therefore great. In addition, a number of islands off the coast offer the potential for use as bases in the construction of major tidal power barrages enclosing very large reservoirs.

The prefeasibility study was concerned with ten study areas, numbered one to ten from north to south.

Study area 1, Seogmo-Do, borders to the north on the Han River which is at this point, the southern boundary of the DMZ, separating South and North Korea. Other study areas to the south are arranged along Kyonggi Bay and continue along the shore line of the Taean Peninsula where various bays and inlets provide opportunities for the development of tidal power. Cheonsu Bay, study area 10, represents the most southerly tidal power scheme presently considered. The mean tidal range at spring tide is 8 m at Incheon and Asan Bay and reduces from there gradually westward into the Yellow Sea. At sites 9 and 10, Anheung and Cheonsu Bays, the mean tidal range at spring tide is in the order of 6 m. These tidal ranges reduce further when going south along the coast line or west into the Yellow Sea.

GENERAL CONCEPTS FOR TIDAL POWER PLANTS AT THE STUDY AREAS

To compare the various sites, a tidal power plant concept was developed which could be applied to all sites. This provided a uniform basis of comparison between sites. The tidal plants thus conceived for each individual site followed a general pattern which, for specific sites, can be improved by responding to specific site conditions.

RATING OF SITES

Numerical energy production models were used as a tool for screening the various alternative tidal power sites under study. For each site, a single effect tidal power plant was projected. For such a plant, that combination of installed generating capacity, sluicing capacity and remaining dike length was determined which would produce energy at the lowest cost per kWh. In this screening process, all sites were compared on the basis of single basin, single effect schemes, operated to produce the maximum amount of energy.

As a result of this screening process, ten feasible tidal power plants were identified with installed capacities ranging from 330 to 1800 MW. The cost of energy ranged from 46 to 78 mills per kWh.

ECONOMIC EVALUATION

For the economic evaluation of the various alternatives, Benefit-Cost (B/C) ratios and Internal Rates of Return (IRR) were determined for each alternative.

In the case of a power project, particularly a tidal power project, the B/C ratio and IRR indicate the relative merits of a project with respect to a reference case. For tidal power studies, this reference case is optimum system development which the electric utility has planned without tidal power (base expansion plan).

The benefit components were assumed to be:

a) Savings in fuel costs by displacing energy which would have been produced by fossil fuel plants.

b) Reduction in the installed generating capacity with respect to the base expansion plan. The reduction will mainly be in peaking plant. This is referred to as "capacity credit".

Costs include only those costs which are directly related to the project.

For the four most economically viable sites, B/C ratios ranged from .73 to .94 and IRR's ranged from 4.4% to 5.6%.

If indirect and intangible benefits, eg., social benefits, are included, the B/C ratio of each site will be greater than the above results.

In Korea it appears likely that such indirect and intangible benefits will provide, in final analysis, the deciding arguments with regard to the choice of site.

It is recognized that within the next few years, noticeable improvements should be feasible in two areas:

a) Improvements in low head turbine designs, and

b) Improved concepts for double basin tidal power schemes to take advantage of unique local conditions.

The development of such new concepts, however, requires time and funding for research. Korea at present is ready to benefit from experiences gained at La Rance, Kislogubsk and Fundy. Korea's first tidal power plant is likely to consolidate the present art of tidal power development, providing a solid basis for further developments from which other plants, to be built in the future, may benefit.

THE DESIGN AND ANALYSIS OF A VERTICAL AXIS OCEAN CURRENT POWER PLANT

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EXTENDED ABSTRACT

INTRODUCTION

Although ocean currents have a low energy density and limitations exist on the amount of extractable energy without seriously affecting the environment, the overall energy potential of ocean currents is enormous. It is presently estimated that the total energy in the world's ocean currents exceeds 5×10^{12} watts. This is more than the energy in the flow of all of the fresh water rivers in the world.

Harnessing this energy for use by modern society is not an easy task. In recent years several conceptual designs for plants that utilize the movement of the ocean currents as a prime mover for an electric generating system have been developed. The plant discussed in this paper consists of a vertical axis turbine designed to match the energy gradient of the flowing current by varying the blade shape. The turbine consists of 30 meter long blades, 3 meters wide located on the periphery of a 30 meter diameter wheel. The turbine is supported from above by a barge allowing for the energy conversion equipment to be out of the water if desired. This makes the plant considerably less complex than recently proposed horizontal axis designs.

This paper discusses the design and analysis of the power plant showing its advantages, problems, and economics. Additionally, various design alternatives are discussed in light of finding a suitable location for the plant which takes into account geographical parameters pertinent to the technical feasibility and economics of the selected design.

Analytical Approach The analytical model developed for this plant utilizes a blade vector diagram with simplifying assumptions to two sets of equations that describe the behavior of the blades as they interact with the ocean current. One set of equations describes the dynamics of the turbine while the other analyzes the kinematics of the blading system. When combined, these equations serve as the basis for a computer program used to optimize blade angles and the relative velocity between the blades and the current to maximize power output. For the blading arrangement used; namely, 12 blades on a 30 meter diameter wheel the average estimated power output is 3 Mwe when the plant is operating in an ocean current of 1.5 m/sec. This corresponds to extracting approximately 40% of the power available in the area swept by the blade arrangement.

Test Program To verify the analytical model and the validity of the simplifying assumptions needed to solve the equations, a two step test program was undertaken. Initially a single blade was tested in a flow channel to establish its lift and drag characteristics. This result was then compared with what was initially assumed in the analytical solution for the blade behavior. The second step in the test program was the construction of a 1 to 70 scale model of the power plant. Tests of the model in a tow tank were performed to obtain torque vs advance ratio curves for the system as well as the total extractable power for various towing speeds. Several test runs were made and the results were compared with the analytical results for the prototype plant output. Although friction of the blade angle positioning mechanism was a problem, general agreement between the analytical model and the scale version of the plant was obtained.

Economic Analysis As currently designed it is expected that the plant would consist of three large vertical axis water turbines mounted on a single barge. Located 5 miles off Miami, Florida in the Gulf Stream the plant would develop a total of 9 Mwe, transmitting the power to shore by a submerged cable. A total capital cost of the 9 Mwe plant is calculated at $24,200,000. Considering operating and maintenence expenses and a yearly cost of money assumed to be 18%, the resultant bus bar cost of 86 mills/kwhr is derived. This is for a plant with an 80% yearly capacity factor. The majority of the cost is estimated to be in building the 110 m x 40 m (50,000 Dwt) barge used as the surface support vessel. Although this cost is high compared to conventional methods for producing electricity, mass producing such plants would greatly reduce the specific cost. In the future as the cost to produce electricity increases, the vertical axis ocean current power plant appears capable of becoming a viable addition to our energy supply.

SOME NEW CONCEPTIONS IN THE APPROACH TO HARNESSING TIDAL ENERGY

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ABSTRACT

This paper outlines a method of converting the energy of ocean tides into electrical and other forms of industrial energy. The main disadvantage of extracting tidal power arises from the low density of tidal power per unit area of the ocean. This leads to the high cost of required investment for the production of substantial volume of the energy.

The aim of the proposed approach is to overcome this by using flexible, light structures for the water barriers instead of the conventional rigid dams and by converting the ocean energy into energy of compressed air.

It is preliminarily estimated that the flexible reinforced plastic barrier should be 20-30 times cheaper than a conventional rigid dam. Due to the limited strength of the materials the water pressure is lower correspondingly to 1-2 metres of water head across the non-rigid dam.

For the expanded low curvature non-rigid dam, practically speaking the vertical reinforcing cables anchored into the ocean bed resist the water pressure. Because of the low water pressure and variable number of vertical cables it is possible to keep the dam stresses within the permissible limits.

The barrier can be designed in such a manner that by means of special floats it becomes the self-supported and self-regulated structural system which can dam a large space of ocean, for example the entrance of Fundy Bay. This conception makes feasible the construction of tidal electric plants of enormous power, providing environmentally clean and inexhaustible energy source.

It should be pointed out that a floated dam cannot be overloaded. Because of the limited buoyancy of the floats they submerge when the ocean waves increase the designed magnitude of a water head. The flexible barrier is practically non-sensitive to sliding foundations and earthquakes. If some sections of the barrier are destroyed, only limited leakages occur which cannot change the overall stability of the structure or impose danger to people.

The power house for the conventional tidal power project usually takes the main part of the investment due to the fact that low-speed bulky hydroturbines require enormous space for their installation. With our approach the energy of the tide is converted into the energy of compressed air by means of specialized chambers which are put on the ocean bed. Ocean water from the dammed region passes through the chamber where it works as a natural piston compressing air in the upper part of the closure. After that the compressed air can be heated and expanded through high-speed compact gas-turbines or any type of reciprocating engines. Such a solution drastically decreases the dimensions of a power house and increases efficiency of the engines.

Compared to other tidal projects, the proposed method offers the following advantages:

1. The decrease of water pressure provides for the possible use of light, flexible plastic barriers which substantially simplifies construction and reduces investment;

2. Navigation and water regulation can be provided without construction of special sluice gates. The plastic barrier can be submerged in periods of equalization of basin levels for those purposes;

3. Because of the comparatively low cost of plastic barriers, the proposal can be applied to any shore location where there is sufficient tide without being connected to special bays with narrow entrances;

4. Thus, the method can be exploited on a small scale and later can be incrementally expanded;

5. High-speed compact air motors require substantially less power house dimensions compared to those with low-speed hydroturbines.

6. The medium driving prime mover is compressed air. This provides the possibility of increasing the power of the station during peak periods by heating of the air. Additionally, it helps to save the engines from rapid corrosion.

7. Inactive time between ebb and flood tide is minimized due to small water head across the dam and, hence there will be more even and continuous power system operation.

8. If for some reason it becomes necessary to recreate the initial environment of the site, it can be done by submerging the barriers or complete removal of the barriers for a period of time.

9. The floats which maintain the upper edge of the flexible dam structure can be combined with the devices for harnessing energy of the water waves. Such a combination increases the efficiency of the system.

The investigation is sponsored by the U.S. Department of Energy.

This approach is grounded in the methods described in the two U.S. patents of Professor A.M. Gorlov: No. 4,095,423 (June 20, 1978) and No. 4,103,490 (August 1, 1978).

OPPORTUNITIES IN WATER POWER DEVELOPMENT

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ABSTRACT

Water power is a clean and renewable, conventional energy resource. Furthermore, most of the water power schemes are often multi-purpose projects serving, besides hydroelectric energy production, to purposes like flood control, irrigation, navigation, etc.; so that they are considered as basic components of the socioeconomic development from various perspectives. It should be put, therefore, special emphasis on the maximal exploitation of water power resources throughout the world.

The water power potential can be assessed at gross, technically exploitable, and economically feasible levels; estimates for the world varies from 44 to 700 thousand TWh/a for the gross, from 6 to 25 thousand TWh/a for the economically feasible water power potential; whereas the latter figures might increase considerably after detailed studies according to changing economic conditions.

Water power schemes are actually generating less than 2 thousand TWh/a, being slightly more than one fifth of the world's total electricity generation and having a modest share of 5% in the total energy balance.

With regard to the scarcity of the conventional fossil fuels, an increase of the share of water power in electricity generation should be anticipated, especially in developing countries, where the large part of the water power potential is still undeveloped.

An investigation of the past trends showed that the period required for the development of 95% of a country's hydroelectric potential will be about 60-70 years. Thus, the last decades of this century and the early decades of the next century may witness a boom of water power development throughout the world.

SESSION 7D

BIOCONVERSION

GASIFICATION OF BIOMASS AS A SOURCE OF SYNFUELS FOR DEVELOPING COUNTRIES

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EXTENDED ABSTRACT

INTRODUCTION

A large number of developing countries would probably solve their energy problems if synthetic fuels could be economically obtained from wood. The main reasons for this conclusion are: a) The per capita energy consumption is very small compared with the developed countries and so, in these countries enough land is available to develop such energy farms; b) The soil quality does not have to be good: usually wood can be grown in areas not convenient for food crops and with small or zero fertilizers requirement; c) The energy requirements for wood plantation and harvesting are much less than for any other crop.

ONE EXAMPLE

One of the most traditional ways of producing liquid fuel from wood is acid hydrolysis, which is used in more than ten plants in the Soviet Union. The energy requirements for the industrial conversion of wood to ethanol (as given by the Russians [1]) are very large: as much as 25 kg of steam/l of ethanol.

A simple energy analysis would tell us that the energy requirements only for the industrial phase of the process is much higher than the energy content of the final product. If we take into consideration the fact that the industrial energy has to be obtained also from wood, which shall be used in electric and steam generation since these plants are not too far away from the energy farm, the following results for the efficiency are found.

Energy requirements for the agricultural phase of wood is 551 Mcal/ha/year [2] as compared with higher than 2500 Mcal/ha/year for sugar cane, cassava and sweet sorghum [3], including transportation for a 30 km distance. [illegible] efficiency boilers consume 750 kcal of natural bagasse (50% organic material, 50% water) to produce 1 kg of steam [2]. Assuming a wood heat content of 4,500 Mcal/ODT, and that 220 l of ethanol can be produced from each ODT of wood, we conclude that each metric ton of wood submitted to hydrolysis processing will require 1,826 Mcal of fuel from wood or approximately 0.4 ODT. This result means that the net alcohol production will be only 156 l/ODT. Using eucalyptus, with a typical yield of 11.8 ODT/ha/year [2], we should be able to produce

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1850 l/ha/year of ethanol with an energy content which can be at least 5 times bigger than all the energy expenditures, including plant construction and installation, maintenance, stillage treatment plus the agricultural (and industrial) expenses.

SYNFUEL ANALYSIS

The possibility of using thermochemical processes seems even more interesting since 1 metric ton of methanol can be produced from 3 ODT of wood including energy expenditure in the industrial phase [4].

Flash pyrolysis, in particular, is a very promising way of thermochemical conversion since it is possible to produce ethylene and other light hydrocarbons which can be easily polymerized to synthetic high quality gasoline [5]. An economical and energy analysis will show the possibility of gasoline precursors production at a cost lower than present day gasoline value (1.00 $/gallon) if raw material can be acquired at 1.00 $/$10^9$ GJ. This price of raw material is inferred from current prices of sugar cane in Brazil, together with an energy analysis which compares the well established costs of sugar cane in that country with the possible costs of wood, produced in large energy farms.

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FUEL WOOD AS A RESOURCE WITHIN SCENARIOS OF COORDINATED ENERGY SOURCES

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EXTENDED ABSTRACT

The concept of energy system trends toward extremes in size and complexity of sources was introduced by Kurstedt, Squires, and Kramer in 1978. The case was made for the acceleration of development of energy-park facilities at one extreme and small locally-controlled sources of energy at the other. Justification was derived from similarity of trends in commerce, business, medical service, and education; recent sharp increases in marginal energy costs; and governmental intervention in the energy scene. It was argued that the key to successful energy use would lie in the intelligent coordination of the extremes. The fuel wood resource is especially useful to demonstrate the concept. Because a high degree of local control is common and wood energy is a misunderstood and misused resource, greater understanding is mandatory.

The progression toward bigger energy production systems will continue. In many cases extensive fuel cycles will be involved. Technological breakthroughs, in fusion for example, will bring on line energy sources that are naturally larger and more sophisticated. Otherwise, for the purposes of centralization, security, fuel cycle management, operational and siting considerations, existing or slightly improved technologies will be involved in larger facilities.

It is in the area of small locally-controlled sources where large strides can be made. Technological improvements, new materials, control and automation advances, and better manufacturing procedures have not yet made their full impact on energy sources such as solar, wood, wind, and water. Some implications are interesting. It is possible for a household, business, or town to totally control the fuel cycle in these cases. Many small enterprises will be established in this area. People are familiar with local conditions regarding limited wood purchase. Serious buying in quantity in most cases has not been tested. Competition in furnishing wood has not become keen. With the opportunity to purchase the energy source and to provide the spare time and effort required to harvest the fuel, the true local prices of these resources has not been established.

Local systems can be independent, coordinated with large systems, and/or dependent upon large systems. A wood system often utilize a redundant backup system. Whether this backup be based on oil or electricity, the

backup system, only used when needed, represents potential demand on these other energy sources. Electric power utilities are committed to provide power when the demand occurs. This requires standby reserves. The capital investment involved in providing little-used facilities increases the unit price for everyone. Policies such as household demand meter requirements become a possibility.

Local control will become in fashion. More people will sacrifice convenience for economics. The effect will be measurable and will be enhanced by government action. More than a fair share of attention will be paid to small systems. Innovation will result and the extent to which small systems will be utilized will be surprising. Most marginal cost advantages will be reaped from the smaller systems. For certain cases, in small systems energy can be derived at present costs of less than $2.00/MBTU (million BTU). In comparison, most energy systems considered today produce energy at a cost ranging from $2.00 to $40.00/MBTU. Probable technological advances will reduce the relative numbers for the smaller systems.

Approximately two quads of wood-derived fuel are burned annually in the U.S. to produce heat, steam, and electricity. Department of Energy estimates project renewable U.S. wood resources to meet a fuel use availability of three to eight quads annually through the year 2000. For comparison, the present U.S. nuclear and hydroelectric energy contributions are each approximately three quads each. Recently, the marginal cost associated with conventional energy systems has increased to a level well beyond the average cost paid by energy consumers. Energy from fuel-wood systems runs counter to this alarming trend and shows significant regional influence on near-term energy scenarios. To supply increased convenience and dependability as needed, the requirement for redundant primarily electrical-based energy systems indicates that fuel wood as an energy resource is a good example application of the "energy system trends toward extremes" concept. Similarities between this application and the application to small coal-fuel systems or mixed solid-fuel systems are indicated.

Wood-fuel systems are in a position to take advantage of general technology advancement in the areas of materials, harvesting techniques, and heat transfer during a period of dormancy in the use of wood energy. Misconceptions are addressed regarding many aspects of wood system use including 1) wood availability as an energy resource, 2) chimney design and safety, 3) pollution and environmental impact, 4) appliance design and efficiencies, and 5) contributions of accessories. Better understanding of wood system use allows evaluation of costs, projections of use, and coordination with other systems at both extremes in size and complexity.

The direct combustion of wood yields a heat source which can produce within a heat generation appliance hundreds of thousands of BTU's per hour in a few cubic feet of volume. This is a factor of three to five less than for oil or natural gas. New fuel conversion techniques will yield fuel forms such as pellets which deliver higher power densities.

Much of the experience on how to burn wood gained years ago is applicable today. However, technology has made great strides during the past 100 years and many of these technological advances are and will continue to make the utilization of wood energy safer, cleaner, and more efficient. There are three main areas of concern in the design of a woodburning appliance: safety, efficiency, and pollution. These are related and good design must consider all three.

Local and state governments are requiring safety listings by a nationally recognized agency for woodburning appliances and accessories. Most woodburning appliances currently being marketed are basically safe. The real safety problems with woodburning appliances are related to the installation and operation of the units. To obtain greater efficiencies and capture some of the ease and convenience taken for granted over the years, changes have been made in many modern woodburning appliances. More experience and great caution are required to properly utilize the new appliances. In a world accustomed to greater safety and security, the probabilities of fire and injury accepted years ago are unacceptable today.

One of the fundamental characteristics of the wood resource is that wood, like petroleum, is an extremely versatile material. There are demands on the material from many quarters. Not only are there demands on this useful material, there are also demands on the land necessary to produce wood. The wood resource, unlike petroleum, has slash and other presently wasted wood material that contains energy.

Many wood fuel facts are often misstated. Wood combustion does pollute, and there exist potentially hazardous compounds in airborne emissions from wood combustion. Conventional chimneys were not constructed with airtight devices in mind, and chimney problems can occur due to the operation of these devices. Due to present flue blockage problems, wood heating devices of improved design to reduce creosote will appear on the scene. Many fireplace accessories such as glass doors and special grates can be counter-productive or nonproductive in regard to heating efficiencies.

True fuel value is a function of fuel power-density, physical configuration, and transportability. Significant advances are being made in these areas; however, a potential dilemma is described in the areas of the development of standards and public information. An evaluation is made of the technical, economic, and operational interrelationships between the fuel-wood energy source and energy systems at the other extreme in size and complexity, such as nuclear fission.

We are confronted with a gigantic, complex, confusing energy puzzle. One piece of the puzzle is wood energy. It is not the whole puzzle as it once was. But the puzzle is not complete without wood energy. The piece has its proper place and it fits appropriately into the other pieces. It is our challenge to determine how the puzzle fits together. The energy system trends toward extremes concept recognizes the need for this fit.

NEW ENGLAND'S INDUSTRIAL WOOD ENERGY PROGRAM

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EXTENDED ABSTRACT

INTRODUCTION

The problems of energy availability and increasing costs of energy have led to national, regional, state, local, and individual efforts to develop economical and environmentally attractive energy resources. Past and continuing experiences have shown the most vulnerable and fastest increasing cost fuel is oil, upon which New England industry is 72% dependent (versus a 29% dependence in the U.S. as a whole). This dependence also means that New England industry pays 53% more on a BTU basis for its energy supply.

In the search for alternatives to help industry and further New England's economic development, the use of wood has been identified as the alternative with the greatest potential impact in the near future. While estimates vary, it is possible that New England's forests could meet much of the energy demands by industry in the rural areas of the region. Cost estimates strongly suggest that such a replacement would be economic, particularly for producers of waste wood or companies near a source of waste wood.

THE PROGRAM

During the past year, the New England Regional Commission (NERCOM) has embarked upon a program aimed at obtaining the necessary background information on the current usage of wood in New England, at analyzing the possible constraints to increased wood use, and at structuring a program to overcome these constraints thereby assisting industries that may wish to convert to wood as an energy source. The significance of this effort has been recognized by the Department of Energy which is currently funding an expansion of this program, as a pilot project, to provide direct technical assistance to industries in New England wishing to convert to wood energy.

Background Research - In 1978 NERCOM commissioned a survey of industries in New England currently using wood fuel and found 150 companies. Collectively, these companies employ over 32,000 people and their boilers have a total output of nearly 4 million pounds of steam per hour. If they were to burn oil, it is estimated they would use at least 34 million gallons of oil each year. Many of these companies produce some sort of wood products and use their own waste as fuel, but others such as a rubber company, a large greenhouse, a hospital, and an electric utility purchase all their wood fuel.

As part of the survey, questions were asked about the companies historical use of wood and any institutional or operating problems which would tend to hinder the use of wood. In almost all cases, companies indicated very few problems with wood fuel and most had, in fact, been using wood for quite some time.

Although in many cases the conversion of wood is economical and the technology is well proven, many firms have not given wood adequate consideration because of lack of information, unfamiliarity with the technology, uncertainty about economics, no knowledge of wood fuel availability, or insufficient funds for assessment of feasibility. Therefore, NERCOM has produced a series of guidebooks to industry to answer the specific needs in the first three areas, is undertaking a major survey of wood residues and is undertaking a direct technical assistance program for industries.

Program Results To Date - So far, the program has been developing the appropriate support material for the full fledged pilot program being funded by the Department of Energy . These include a series of guidebooks, the survey of wood residues, and the development of a computerized financial analysis model.

The series of technical documents provide an introduction and much of the detailed information which a company would need to seriously consider wood as an alternative energy source:

> Why Wood? An Introduction for Potential Industrial Wood Boiler Users.
>
> A Users Guide To: Fuel Wood Availability and Fuel Procurement Strategies.
>
> A Users Guide To: Legal and Institutional factors affecting the use of Industrial Fuel Wood Boilers in New England.
>
> A Users Guide To: Wood Boiler Equipment and Engineering.
>
> A Users Guide To: Institutional and Regulatory Factors Affecting the Use of Wood Fired Cogeneration Facilities.

NERCOM also developed a listing of 2400 possible sources of supply of waste wood in New England. These firms were surveyed, with a 50% response rate, to get a better handle on the quantity, quality, and availability of waste wood throughout the region. This information is being put on the computer to provide a means of readily accessing the data within a given radius of an individual company seeking wood residues.

The financial analysis model is an interactive system providing the individual company with an easy, standardized means of evaluating a wide range of parameters which effect the decision to convert to wood. Input parameters include oil and wood fuel costs, inflation rates, conversion costs, Federal and State tax incentives, and loan rates. Outputs of the model include years to payback, rate of return, and a cash flow analysis.

Even before the full technical assistance program has been able to get underway, assistance has been provided to several firms in New England. All of these analyses show that conversion to wood is an extremely attractive investment for their companies and many of these companies are proceeding on their own toward conversion.

BIOLOGICAL SOLAR CELLS

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Recent reports have demonstrated the possibility of employing photoactive biological components in photoelectrochemical cells (1). Such cells have used chloroplast membranes, photosystem I particles, purple membrane fragments containing bacteriorhodopsin, bacterial reaction centers, and chlorophyll. In most cases the biological component was incorporated into liposomes or bilayer lipid membranes and stability enhanced by the use of polymers or lipid-impregnated filters. Unfortunately, the geometry of such systems is cumbersome because the photoelectrochemical cell must be divided into two compartments. Chlorophyll and chloroplast membranes also have been deposited onto electrodes thus simplifying the cell, but the photoeffects have been either small or rather unstable.

Since photosynthetic bacterial reaction centers (RC's) are known to be relatively stable and can convert up to 20% (theoretical limit for air mass 1.2) of incident sunlight to chemical energy in the form of a charge separation, we have suggested (2) that RC's might be deposited directly onto electrodes. We report here the immobilization of Rps. sphaeroides RC's on various types of conductors. Photovoltages and photocurrents obtained from RC-coated platinized platinum electrodes are not due to coupling of biological charge separation because the photoeffects are not eliminated by autoclaving. They are probably the result of a "biological" Dember effect. RC-coated sputtered carbon and SnO_2 electrodes exhibit photovoltages and photocurrents as high as 45mV and 0.2 μA, respectively. In the case of SnO_2 RC electrodes, autoclaving eliminates the photocurrent and leaves a small residual photovoltage of opposite polarity. Thus, it appears that charge separation within RC's can be coupled to some types of electrodes and that the system might serve as a model for future organic photovoltaic devices.

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SESSION 7E

ENERGY CONSERVATION

New Piping Technologies for District Heating Applications

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Abstract

District heating (D/H) is a practical technology that is experiencing widespread implementation in Europe. The main thrust of the technology is energy conservation by utilization of low grade heat from power plants, geothermal resources and other secondary energy sources as a substitute for the combustion of fossil fuel for space and water heating. Studies of the prospects for D/H in the U.S. are encouraging, but all demonstrate that pipe installation, with current technology, presents great obstacles to widespread implementation of D/H in the U.S. and other countries.

Existing D/H piping systems, as developed in Europe, have shown long service life and reliable operation. However, attention has been primarily focused on peripheral structures around the pipe, i.e., anti-corrosion protection of metallic pipes and anti-moisture penetration of thermal insulation, and not on the pipe itself. Current piping technology generally leads to great installation expense and prolonged disruption of street use patterns.

Developments in nonmetallic materials and tunneling technology are shown to hold great promise for minimizing both technical and economic obstacles to D/H. A wide class of composite materials, among them polymer concrete, display desirable thermal and mechanical properties as pipe material. These are discussed in the context of requisite properties for novel installation

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techniques. Two installation methods are envisioned. For lightly populated areas, installation in open trenches may be employed. Factory prefabricated pipe, consisting of two layers of concrete which encapsulate the insulation, can be buried directly in trenches. For intensely populated areas, horizontal tunneling and automatic tunnel lining with rapid setting polymer concrete and subsequent insulation and concrete layers can be used. These methods, which have been used in other applications, eliminate the need to open streets except where junctions are required, minimize soil compacting, and greatly reduce the number of joints. Details are presented on the design and projected costs of D/H piping systems based on such technology.

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EXPERIMENTAL RESULTS FROM THE FIRST YEAR OF OPERATION OF THE SOLAR GROUND COUPLING RESEARCH FACILITY AT BROOKHAVEN NATIONAL LABORATORY*

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EXTENDED ABSTRACT

Results from the first year of operation of the solar ground coupling research facility at Brookhaven National Laboratory (BNL) are presented. Eight experiments which are first generation ground coupled heat transfer and storage devices for a solar source heat pump system have been operated since December, 1978. A computer program called GROCS which models the heat transfer between these devices and the earth has been written (and subsequently integrated with the solar energy system simulation program TRNSYS by John W. Andrews). In this paper the ground coupling research program, the first generation experiments, and the underground heat flow model GROCS are described. Experimental results from the winter of 1978-79 are presented and compared to model predictions. Results from the summer of 1979 are also discussed.

The goal of our research program is to determine the feasibility of ground coupling for solar source heat pump systems, and if feasibility is demonstrated, to specify the optimal configurations of ground coupling devices for various climates, sites, and applications in a "Handbook". A key step toward this goal is our experimental and analytical research at BNL which is designed to:

(1) Determine the feasibility of using ground coupling given the local (Long Island) climate and geography.
(2) Develop experimentally validated computer models of ground coupling. This is paramount as reliable models facilitate the design of ground coupling devices on paper with confidence.

Our experimental effort, conducted at the solar ground coupling research facility constructed in 1978 at Brookhaven National Laboratory, consists of eight major independent experiments (space is reserved for four others). Four of these experiments involve buried tanks, and four use buried serpentine coils of 1 1/2 inch diameter flexible polyethylene pipe in various configurations and lengths. Heat is added to or removed from each experiment by hot water heaters or heat pumps. The amount of heat added or removed is determined by a computer program which simulates all parts of the solar system (collectors, heat pump, climate, load and the ground coupling device). Each experiment is run according to a different "scenario" or "control strategy". Some of the strategies investigated via

these scenarios are:
(1) Summer and fall collection of solar energy for winter use ("quasiannual storage").
(2) "Emergency" heat from the earth when solar energy is not available.
(3) Summer dumping of space cooling rejected heat.
(4) Variations in collector area.
In addition to the eight major experiments discussed above, other experiments have been conducted to determine ground thermal conductivity, heat capacity, diffusivity, and moisture content.

Analytical heat flow modeling proceeds in parallel with the experimental work. Since the realm of interesting underground heat flow problems that can be solved by hand is limited, a computer program called GROCS, which solves finite difference heat flow equations over a system of "blocks" of earth, has been written. Each block is a volume of earth whose size and shape are determined by a hand-drawn model. There are three advantages to a block-type model:
(1) Useful problems can be solved with a short, simple, and economical computer program.
(2) Adequate accuracy can be obtained. Naturally occurring ground inhomogeneities limit the accuracy of any model which relies on bulk thermal properties to about 10%. Therefore, it is a waste of time and money to use fine mesh models "more accurate" than this limit.
(3) New ground coupling configurations can be studied by creating new hand-drawn models, a process which takes a few hours.

* Work performed under the auspices of the U.S. Department of Energy, Systems Development Division, Solar Applications, Office of Assistant Secretary, Conservation and Solar Application.

COGENERATION, CONSERVATION AND COMBUSTION TURBINES

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ABSTRACT

Until such time as renewable resources can assume the major, or entire, burden of supplying the world's energy needs, we must continue to rely on currently conventional sources. These include coal, petroleum, natural gas, uranium and hydropower. The timing of the transition is in the next 30 to 50 years depending on which estimate is used. Regardless of the precise manner and timing of the transition, it is clear that a substantial length of time must be included in planning to assure an uninterrupted supply of energy. If one takes as a given that the supply of fossil fuels is finite, it is reasonable to plan for their most efficient use and to manage their consumption consistent with present and future needs.

Conservation of resources is a generally accepted concept of management, although the degree to which it is applied is the subject of sometimes lively debate. One of the techniques by which conservation can be applied in the use of energy is energy cascading whereby a stream of energy is directed through two or more processes in serial fashion. Greater efficiency of use is possible in the combination than if separate energy streams were provided for each process. The concept has been in use in industry for many decades. Installations providing work from an engine and using its exhaust to perform heating functions were known as combination plants. Recently the concept has enjoyed renewed interest under the coined name "cogeneration" presented in President Carter's National Energy Policy proposal to the people of the U.S. in April 1977.

Any heat engine is theoretically fit for cogeneration application, but some are better suited than others. In this paper, the combustion turbine is shown to be the prime mover most broadly suited for cogeneration applications. This conclusion is based on the examination of thermodynamic cycles upon which various heat engines are based. The concept of availability to do work is distinguished from heating potential. These are then applied to cogeneration cycles to form the basis of the thermodynamic conclusion.

A heat engine is one which accepts thermal energy and converts part of it to mechanical energy (work). The portion not converted to mechanical energy is rejected to the engine's surroundings. N. L. S. Carnot, a French scientist, conceived an ideal heat engine circa 1820 whose efficiency was the highest attainable. Others have been devised with equal efficiency, but none has a higher efficiency. The Carnot cycle is the simplest and the most easily understood, hence it is the one most often referred to in the technical literature. When supplied with energy, some of that energy is converted to mechanical work and the remainder rejected to its surroundings. A natural question to ask is "why is just part of the supplied energy converted to work; why not all of it?" The answer is that the laws of nature will not permit a heat engine which can do that. The law most often referred to in connection with this phenomenon is the Second Law of Thermodynamics. It is not our purpose to explain that law in this paper--that is the subject of much lengthier treatises. The proper object of heat engine design is to maximize the use of the energy supplied and minimize rejected energy. That is precisely what the Carnot engine does.

The efficiency of the Carnot engine is dependent only on the temperature at which energy is received and discharged. The nature of the working fluid does not matter in the calculation of efficiency. The relationship is simple:

$$\text{Efficiency} = \frac{\text{Inlet Temperature - Exhaust Temperature}}{\text{Inlet Temperature}}$$

where the temperatures are on the absolute scale. Observe that the efficiency can be improved only by raising the inlet temperature and/or lowering the exhaust temperature. Materials limitations usually determine the maximum inlet temperature. The lowest available exhaust temperature is that of the surroundings of the heat engine, the ambient temperature.

There are institutional aids and barriers to cogeneration. The importance of enhancing the aids and overcoming the barriers is related to the need for conservation. In order for cogeneration to be effective, there must be a simultaneous need for both power, either electrical or mechanical, and process heat. Although this truism seems immediately self-evident, enthusiasm for its energy conservation potential quite often blots out its light. The basic reason for the truism is economic. Unless the needs are simultaneous and in proportion to each other, there will be times when capital equipment will lie idle but continue to incur capital charges. Since the cogeneration plant must spread its expenses over actual production, idleness adds to the cost of that production over and above the cost for operation and fuel. Every piece of capital equipment faces this problem, but when the idleness and its costly consequence become too great, the market for the equipment dries up. This is precisely what has been occurring with industrial cogeneration projects.

These "natural" barriers to cogeneration are being supplemented by institutional disincentives even now being erected. The Power Plant and Industrial Fuel Use Act (FUA), one of five acts which comprise the National Energy Act (NEA) passed in the Fall of 1978, disallows, for its cost test, accelerated depreciation and investment tax credits for cogeneration projects which contemplate using oil or gas as fuel. The Natural Gas Policy Act (NGPA), another part of the NEA, mandates increases in the price of gas to industrial users to cover the cost of incremental supplies such as LNG and synthetics. Furthermore, industrial users are at the bottom of the priority list which further jeopardizes investments based on the use of gas. The NGPA also places intrastate gas under Federal control which further removes possible secure sources of supply. The Public Utilities Regulatory Policy Act (PURPA), also a part of NEA, seeks to place all rate and other regulatory matters in the hands of the Department of Energy. This will tend to discourage joint industry-utility projects for fear that the industrial partner will come under additional regulation and not receive fair value or return on investment. Another danger in PURPA is that utilities may find that their expenses in behalf of cogeneration may be disallowed in rate proceedings in case they are not financial successes or, conversely, used to leverage rates for other customer classes. The tax and conservation portions of NEA contain incentives which could be applied to cogeneration projects, but they are negated by the other three acts.

THE BRIDGEPORT RESOURCE RECOVERY SYSTEM

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EXTENDED ABSTRACT

The myth that the United States has been blessed with an unending supply of natural resources is rapidly changing into the reality that our supplies are in fact limited. The growing population and improving standard of living deplete phenomenal quantities of natural resources while contributing to ever-growing waste disposal problems.

In the days when energy sources and virgin materials were readily available, there was little incentive to recover secondary materials from waste. The cost of virgin materials was significantly lower than the cost of recovering or preparing them from the waste stream. Consequently, disposing of refuse in open dumps and landfills was an acceptable practice.

Until very recently dumping sites were conveniently located near urban centers in areas where the cost of land was relatively low. With the advent of "urban sprawl", however, the cost of land began to rise, forcing disposal sites farther and farther from the refuse-generating urban centers.

Increased land and hauling costs have reduced the gap between the expense of disposal and the expense of recovery. Economic barriers to resource recovery have been lowered.

Moreover, social and environmental considerations dictate that we can no longer afford to lose our steel, aluminum, tin, glass and paper products to the oblivion of the garbage dump.

THE PROJECT

When the State of Connecticut recognized that refuse disposal was a problem of phenomenal proportions it created a statewide authority to determine a long range solution.

The Connecticut Resource Recovery Authority (CRRA) was charged with the responsibility of implementing a plan for waste disposal and resource recovery throughout the State. To do this, the CRRA was given the power to enter into contracts with private industry for the construction and operation of resource recovery facilities, to enter into contracts with local municipalities for disposal services, and to issue bonds for financing construction.

In May, 1974, after receiving over 60 statements of qualification, the CRRA selected Combustion Equipment Associates (CEA) to construct a resource recovery facility in Berlin, Ct. Occidental Petroleum Corporation (OXY) was selected to construct another facility in Bridgeport, Ct.

The two companies, both leaders in the environmental controls industry, combined their resources and technologies in the Bridgeport project and formed CEA/OXY Resource Recovery Associates.

The Bridgeport Resource Recovery System is an integrated, regional approach to solid waste management made possible through a unique combination of government initiative and industry commitment.

Nine municipalities in the greater Bridgeport area are participating in the project. By working together with the CRRA and CEA/OXY Resource Recovery Associates in implementing the regional plans, the communities have assured themselves a long-term economic solution to their waste disposal problems.

The system consists of:

- six local transfer stations for the collection of refuse,
- the Central Processing Facility in Bridgeport, and
- the United Illuminating Company, a local utility which has agreed to purchase the fuel product.

The Central Processing Facility employs CEA's proprietary ECO-FUEL II technology. This chemical and mechanical method of treating solid wastes yields ECO-FUEL II, a high quality, clean-burning fuel that can be stored indefinitely and transported economically. No burning of refuse occurs in the process; no smoke or water effluent is created.

Combined with OXY's proprietary recovery techniques for glass and metals the Bridgeport plant is a totally comprehensive resource recovery center.

Based on a maximum capacity of 2200 tons per day, the plant will produce 1400 tons of aluminum, 47,000 tons of ferrous metals, and 335,000 tons of ECO-FUEL II annually.

The ECO-FUEL II will be fired at United Illuminating's Bridgeport Harbor Station displacing approximately 850,900 barrels of expensive fuel oil annually.

The State of Connecticut along with the efforts of CEA/OXY Resource Recovery Associates have succeeded in turning an environmental bane into a social asset. The Bridgeport Resource Recovery System is a model of public/private participation and regional planning that will impact all future resource recovery projects.

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TRASH TO ENERGY

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INTRODUCTION

The rapid depletion of fossil fuels, particularly petroleum and natural gas, makes consideration and development of alternative sources of energy a matter of great importance. One of the most promising alternatives may be found in the 3.5 million tons of solid waste material discarded by our society every year.

TECHNOLOGY

The low pressure, commercial, industrial, process, and steam heating markets cannot be serviced in the future by new nuclear or other fuel sources. The time frame required to develop synthetic fuels can be shortened by applying known and proven technology for firing a host of waste materials. The technology has long been available for burning bark, sawdust, chipped wood, basasse, et cetera.

The objectives of this conference are the subject of this paper; that is, the technological, social, and environmental facets of energy. However, in the solid wastes industry, the most significant factor is the political reality of instituting major energy recovery programs in an urban environment.

The technology available today for burning waste as a fuel may be represented by flue-fed boilers, mass burning systems, semi-suspension firing, fluidized bed reactors, slagging furnaces, pure oxygen systems, gasification systems, and pyrolysis. Direct firing techniques are in competition with efforts to produce refuse-derived-fuel concepts (RDF). Attempts at RDF production for firing as a substitute fuel in existing gas and oil firing equipment are ambitious. The challenge lies in matching the appropriate technology with the available market. The result is a tug of war among proprietary systems seeking to gain competitive advantage by signing contracts rather than employing an intelligent assessment of the proper technology relative to market needs.

The sociopolitical challenge is the true hurdle for this industry. Although scientists and engineers have produced marvels that put man on the moon, we have yet to identify the combination of disciplines needed to provide advice which will instill confidence in the public and its elected officials. It is this credibility that will allow advancement of solid waste energy programs. A scenario will be suggested in this paper which would make such energy plants a reality.

Environmentally there is a great opportunity to demonstrate valuable returns from a substitute fuel that is now a total waste. Materials recovery takes place in front-end systems, and one of our most valuable non-renewable resources is extracted in the form of ferrous metal and recycled back into the economy. Paper products, representing over 60% of the solid waste stream, are consumed and converted to steam for commercial use. In addition, when compared to oil- or other petroleum-fired systems, cellulose or paper is a clean, sulfur-free fuel. Environmental analyses report an overall reduction in pollution when firing with waste fuel. The major stack efficient from waste firing consists of fused clay particles and some carbonaceous material. The technology of electrostatic precipitators, reaching efficiencies of 99%, has been proven in half a century of use in fuel burning applications.

ECONOMICS

The economics of energy recovery systems are extremely attractive. At equivalent prices for fossil fuels with an escalator of 6% per year, a complete pay back for a low pressure commercial energy recovery system may be realized in 15 years. Replacement of the mechanical equipment may be required in 15 years, but over 50% of the capital investment is in bricks and mortar with amortization period of 30-50 years. Truly a profit potential exists. We can, therefore, conclude that more than ample incentive exists to develop this alternative source of energy.

We are looking to this conference to help enlighten the academic community, our industry, and our government as to the enormous potential of solid waste burning as an alternative source of fuel for today and the generations to come.

ENERGY CONSERVATION BY PASSIVE SOLAR HEATING

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EXTENDED ABSTRACT

INTRODUCTION

Residential space heating consumes approximately 11.4% of the total energy need in the United States. Insulation and solar heating can reduce the energy requirement by a significant amount at a reasonable cost. However, even for well-insulated houses, it is economically unrealistic to provide 100% space heating by solar energy. In order to optimize the benefit to cost ratio, it is necessary to investigate the potential energy savings of a very simple solar heating system which requires the minimum amount of additional cost for construction and maintenance.

DESIGN AND CONSTRUCTION

Many possible configurations were studied. A house, which uses south facing windows as solar collectors, appears to be the most economical configuration for immediate applications in the northern hemisphere. Using the solar energy data given by the ASHRAE Handbook of Fundamentals, an equivalent collector efficiency of 61.2, 66.3, and 68.9 percent can be reached by such a passive solar house located at 32°, 40°, and 48° Northern latitudes, respectively, during the months of December and January when the solar position is in the vicinity of the Tropic of Capricorn. The amount of solar energy entered the south facing windows decreases as the sun moves northward and reaches a minimum during the months of June and July when the solar position is in the vicinity of the Tropic of Cancer. However, even the minimum amount of solar radiation is undesirable during summer months when cooling is needed. An appropriately designed shading structure can keep the south facing windows in the shaded area during summer time. A permanent structure, such as a roof overhang with an appropriate width at a given height above the windows, can provide the desired shade as well as the requirement of minimum construction and maintenance cost. The same principle applies to residential dwellings located at the southern hemisphere with north facing windows.

A single family dwelling was constructed using conventional construction method and recommended insulation for the area at 38°N latitude in the central region of the United States. 70% of the total window areas are facing south with a 2-foot wide roof overhang at a distance of 6 inches above windows for the upper level and a 4-foot wide deck at a distance of 2-feet above windows for the lower level. The maximum solar collector area is 6% of the total living area on the 21st day of December. The minimum solar collector area is zero during the period between the 6th of May and the 6th of August. An estimated energy saving of 20 to 30 percent was obtained for the winter months assuming sunny days were 50 to 75 percent during that time. Higher percentage of energy savings could be achieved by increasing the area of south facing windows. However, solar energy storage and distribution systems might be needed to prevent overheating. Consequently, additional cost for construction and maintenance would be necessary.

RESULTS AND CONCLUSIONS

Testing was conducted between October 1978 and April 1979. Indoor and outdoor temperatures were recorded continuously. Solar intensities and solar collecting areas were measured hourly. The measured percentage of sunny days ranged from 36% in March to 63% in December with a seasonal average of 46%. The tested house has 4,500 ft^2 living area with a maximum of 270 ft^2 window area facing south as solar collectors during the months of December and January. Since there is no energy storage, the possibility of overheating by solar energy was investigated. A maximum temperature increase of 6°F was recorded between 10:00 a.m. and 3:00 p.m. on December 15, 1978 when the house was heated by solar energy alone at an outdoor temperature range between 38 and 48°F as well as on January 3, 1979 at an outdoor temperature range between 10 and 23°F. Maintaining a minimum temperature of 68°F, the house required 116,940,000 Btu for space heating during 1978-1979. 23,700,000 Btu, or 20.3% were supplied by passive solar heating through south facing windows. Table 1 summarizes the estimated and measured results of the monthly total energy requirement as well as the monthly solar energy supplement. It can be seen that the methods of estimate for energy requirement and for solar gain are reasonably accurate, while the actual percentage of sunny days varies substantially from the statistical average. Since weather is yet beyond the stewardship of man, it is necessary to allow a reasonable tolerance in designing solar heating systems. Using the tested house as an example, this study provides the essential design information and a simple method to estimate energy savings for passive solar heating of residential dwellings at various latitudes. The purpose is to make the information available to consumers for evaluating the economic incentives of using either an active or a passive solar system for energy conservation.

TABLE 1, COMPARISON BETWEEN ESTIMATED AND MEASURED ENERGY REQUIREMENT

MONTH	AVE. OUTDOOR TEMP. (F)		ENERGY REQ'D (10^{-6} Btu)		SOLAR ENERGY (10^{-6} Btu)				SOLAR SUPPLIMENT (%)		
	EST	MEAS.	EST.	MEAS.	EST.		MEAS.		EST.		MEAS.
					50%	75%	(%)		50%	75%	
OCT	60	60.3	6.20	5.75	3.97	5.76	(59)	4.66	64.0	92.9	81.6
NOV	50	51.1	19.60	17.13	4.85	7.26	(36)	3.52	33.0	49.4	31.6
DEC	30	31.2	24.18	23.62	5.19	7.79	(63)	6.53	21.5	32.2	27.6
JAN	15	16.4	33.48	32.63	5.13	7.70	(40)	4.07	15.3	23.0	12.5
FEB	25	27.4	24.92	23.42	3.78	5.67	(42)	3.16	15.2	22.8	13.5
MAR	45	42.6	15.19	16.68	1.91	2.86	(36)	1.38	12.6	18.8	8.3
APR	60	53.7	6.00	3.71	0.42	0.63	(45)	0.38	7.00	10.5	10.2
TOTAL (AVE %)			129.57	116.94	25.25	37.16	(46%)	23.70	(19.5%)	(29.1%)	(20.3%)

INDOOR TEMPERATURE WAS MAINTAINED AT 70 ± 6 °F FOR THE PASSIVE SOLAR HOUSE OF 4500 FT^2 LIVING AREA LOCATED ON 38°N IN THE CENTRAL REGION OF THE UNITED STATES

Energy Conservation in Neighborhood Revitalization

ABSTRACT

Submitted for

2nd Miami International Conference on
Alternative Energy Sources

V. Hartkopf

The major purpose of the paper is to discuss the potential role of inner city housing rehabilitation (including retrofitting existing and constructing new housing units) can play in national, regional and local energy conservation efforts.

Attempts will be made to quantify the potential energy conservation impacts of inner city rehabilitation. The energy requirements (including initial energy investment for materials, construction, site and service facilities and future operational energy requirements) for the delivery of a set number of housing units in a new subdivision will be compared to the energy required in delivering the same number of units in a declining, presently underpopulated inner city neighborhood. Associated potential savings such as transportation will be mentioned.

In addition to this discussion, the paper will focus on some of the projects concerning urban rehabilitation conducted in the Advanced Building Studies Program (ABS) at Carnegie-Mellon University. The ABS program, which is jointly sponsored by the Departments of Architecture, Civil Engineering and the School of Urban and Public Affairs, conducted among others, the following projects:

1. An Energy Efficient House for a Declining Neighborhood, ABS Student Report 1976=77.
   In the project, active and passive solar energy systems are integrated. The predicted energy performance of the design has been closely analyzed and the actual performance will be monitored once the house is built. Construction is scheduled to begin in July 1978. (see isometric)

2. Energy Efficient Redevelopment of an Inner City Block.
Studies concerning the planning, design, construction and operation of the rehabilitation (including rehabilitation of vacant housing and retrofit of existing structures as well as the construction of new housing units) of an inner city block are currently underway in the ABS program.

The paper will present several alternate designs, their respective predicted energy performance and necessary initial energy investments. The designs are responsive to economic, financial, social, legal, aesthetic and energy related constraints.

The second project is to lead to a demonstration project; also with the cooperation of various agencies of the city of Pittsburgh, financial institutions, a developer and the community, presently being secured. A proposal to the Department of Energy has been submitted.

AN ASSESSMENT OF THE USE OF CHEMICAL REACTION SYSTEMS FOR THERMAL ENERGY TRANSPORT

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EXTENDED ABSTRACT

INTRODUCTION

This paper describes the work performed by Gilbert Associates, Inc. under EPRI/Sandia Lab. contracts on technical and economic assessments of the use of chemical reaction systems (CRS) as a means to transport thermal energy [1,2]. In the advanced CRS concept, waste heat is used to drive a reversible chemical reaction in the endothermic direction. The reaction products are transported via pipelines to another location where the reverse reaction is conducted to release the exothermic heat of reaction for intended application. The reaction products are then returned to the heat source via another pipeline to complete the closed loop.

This paper presents the work on the Benzene/Cyclohexane (B/C) system. The assessment of this CRS includes: (1) conceptual designs of the CRS and the Therminol-60 alternative system (a sensible heat transport system); (2) calculation of life cycle cost and analysis of its sensitivity with respect to system capacity, transmission distance, and plant life; (3) comparison of these two systems, and (4) analysis of the CRS market potential.

TECHNICAL HIGHLIGHTS

In the B/C CRS, waste heat from the cement kiln exit gas (1300^{o}F) is used to decompose (endothermic reaction) cyclohexane into benzene and hydrogen in a catalytic reactor. The benzene and hydrogen are transported in separate underground pipelines over a distance of 10-100 miles to the user end where they are combined (exothermic reaction) to regenerate cyclohexane. The liberated heat is used to produce 400 psia steam. The reaction product, cyclohexane is returned to the endothermic catalytic reactor via another pipeline to complete the closed loop.

The T-60 system was designed for the same waste heat source and 0-25 miles transmission distance, using Therminol 60 heat transfer fluid. The T-60 system delivers sensible heat to the user end via insulated aboveground pipeline for hot water production at 446^{o}F.

A comparison of the CRS and T-60 system is given in Table I.

TABLE I SYSTEM COMPARISON

	B/C CRS	T-60
Thermal Product	High pressure steam	Hot water
Potential Application	Long distance	Short distance
Pipeline	Three pipelines; no insulation required	Two pipelines; one requiring insulation
Designed Operation	Complex	Simple
Thermal Efficiency	Remaining fairly constant with distance	Decreasing rapidly with distance

ECONOMIC ANALYSIS

Base Case Economics For both systems, the total capital requirement, operating cost, and life cycle energy cost were developed at the base case conditions (design capacity, 25 mile transmission, and 30-year plant life). The results are summarized in Table II.

TABLE II ECONOMIC SUMMARY FOR BASE CASES

	B/C CRS	T-60
Annual Heat Recov., 10^9 Btu	770	770
Thermal Efficiency, %[(a)]	47.0	54.9
Transmission Distance, Miles	25	25
Capital Requirements, 10^6 $		
Plant	7.366	12.014
Transmission	15.483	18.823
	22.849	30.337
Total Oper. Cost (1st Yr), 10^6 $/Yr	1.6171	0.7462
Life Cycle Cost, $/$10^6$ Btu[(b)]	8.40	7.63

[(a)] Defined as: (Useful Heat - External Energy) x 100/Reject Heat

[(b)] Based on a 30-year plant life, the levelized capital charge rate is 0.146 and the levelized O&M factor is 1.935. All costs are on a mid-1979 basis.

Sensitivity Analysis The sensitivity of various costs was analyzed with respect to changes in system capacity, transmission distance, and plant life for both systems. The 100 mile transmission distance was not analyzed for the T-60 system because of its excess heat loss (about 4^{o}F/mile) over this distance. The sensitivity of life cycle cost with respect to changes in capacity and transmission distance is summarized in Table III.

TABLE III SENSITIVITY ANALYSIS - LIFE CYCLE COST ($\$/10^6$ BTU)

	Capacity (Relative Factor)				Distance (Miles)			
	0.5	1	2	5	0	10	25	100
B/C CRS	10.82	8.40	6.70	5.18	-	6.39	8.40	20.26
T-60	11.56	7.63	6.34	4.90	1.86	3.97	7.63	-

The cost sensitivity was also analyzed for two plant lives, 20 and 30 years. The analysis indicates that the plant life does not have a significant effect on the life cycle cost.

Market Potential Two economic criteria were used to assess the market potential of the B/C CRS: the cost of recovered energy compared with (1) the cost of supplying the energy by burning fuel (i.e. natural gas and oil) and, (2) the cost of energy recovery from the T-60 system. The analysis shows that the CRS is nearly competitive with its alternative system. However, it is not economic when compared to purchased fuel unless fuel costs escalate significantly. Assuming 2.4%/yr real escalation of fuel costs and 6%/yr general inflation, the CRS would be economical below about 20 miles transmission in the 1980-2000 period.

CONCLUSION

In short, over the capacities and transmission distances studied the Benzene/Cyclohexane CRS is not economical at present time. However, it has the potential for becoming economical in selected applications within the 1980-2000 period, if fuel costs escalate significantly.

REFERENCES

1. Gilbert Associates, Inc., An Assessment of the Use of Chemical Reaction Systems, Phase I Final Report, December 1978, prepared for Electric Power Research Institute under Contract RP 1086-1.

2. Gilbert Associates, Inc., An Assessment of the Use of Chemical Reaction Systems, Phase II Final Report, June 1979, prepared for Sandia Laboratories.

ABSTRACT

TWO METHODS OF CONSERVING FUEL

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The first method is to substitute solid waste hydrocarbons for part of the coal as fuel. The advantage is a cleaner burning fuel as well as a lower content of CO_2 in the combustion products. The waste is mainly polyethylene and polypropylene used as disposable milk containers, films and other containers. The second method of conserving gasoline and electricity is to use perennial ground cover plants and low spreading evergreens instead of grass lawns. Regular mowing of lawn requires use of high amounts of gasoline or electricity during most of the year.