JHU/APL
EQR/80-3

Quarterly Report

ENERGY PROGRAMS

at The Johns Hopkins University Applied Physics Laboratory

JULY—SEPTEMBER 1980

THE JOHNS HOPKINS UNIVERSITY ■ APPLIED PHYSICS LABORATORY

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Johns Hopkins Road, Laurel, Maryland 20810

FOREWORD

The Applied Physics Laboratory issues the Quarterly Report series to provide the defense establishment and the scientific community with current awareness of selected APL activities. At present, the Quarterly consists of the following volumes:

<u>Programs</u>	<u>Report Designators</u>
<u>Department of Defense Programs</u>	
Research and Development	RQR
Exploratory Development for Missile Propulsion	DQR
<u>Civil Programs</u>	
Energy	EQR
Biomedical Research, Development, and Engineering (Annual Report)	MQR

The nomenclature for the APL Quarterly Report is as follows. The designation for Quarterly Report, "QR," is preceded in each case by a letter that indicates the volume's program area. After the "QR," a virgule is followed by a year indicator (e.g., "77-") and a number from 1 to 4 to specify the calendar quarter.

The format is flexibly designed so that most technical articles can be presented on a single sheet of paper. Each article is given a section number (e.g., §24), which applies to the current Quarterly only. Each article is keyed to its major program area (e.g., Research and Exploratory Development), its technical instruction (e.g., Amorphous Semiconductors), its budget code (e.g., A3), the Laboratory Group or Groups that performed the work (e.g., BBE), and the agency that supported it (e.g., SEA-62R).

Certain Laboratory programs, including some that report a portion of their activities through the Quarterly Report, use document series other than the QR to report the bulk of their activities. Those series are available only to individuals and organizations that are directly concerned with the specific programs involved.

Requests for Quarterly Reports should be directed to: Supervisor, Technical Publications Group, Applied Physics Laboratory, Johns Hopkins Road, Laurel, Maryland 20810.

PREFACE

The Johns Hopkins University Applied Physics Laboratory, under contracts with several agencies of the federal government, is engaged in developing energy resources, utilization concepts, and monitoring and storage methods. This Quarterly Report summarizes the work on the various tasks as of 31 September 1980.

The Energy Quarterly Report is divided into four sections. The first, Geothermal Energy Development Planning and Technical Assistance, supported by the Department of Energy/Division of Geothermal Energy (DOE/DGE), contains reports on the progress of geothermal-related tasks on which effort was concentrated during the quarter.

The second section, Operational Research, Hydroelectric Power Development, supported by the Department of Energy/Resource Applications (DOE/RA), contains reports on small-scale hydroelectric investigations in the southeastern states.

The third section, Seismotectonic Investigations, supported by the Reactor Safety Research Division of the Nuclear Regulatory Commission (NRC), reports on neotectonic investigations of the Manhattan Prong.

The fourth section, Energy Conversion and Storage Techniques, contains three articles. The first is an evaluation of the Einstein refrigerator, supported by independent IR&D funds. The second concerns OTEC pilot plant performance calculations, supported by the Department of Energy/Division of Central Solar Technology (DOE/CST). The third, describing a study of landfill methane recovery, is supported by the National Park Service.

 

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GEOHERMAL ENERGY DEVELOPMENT PLANNING AND TECHNICAL ASSISTANCE

\$15

Development of Geothermal Energy in the Eastern

U. S. ZJ70CQO

Support: DOE/DGE

K. Yu, R. von Briesen, J. E. Tillman, and F. C.

Paddison

July-September 1980

GEOHERMAL TECHNICAL ASSISTANCE

APL has been designated by the Department of Energy's Division of Geothermal Energy (DOE/DGE) as a center for technical assistance for the application of geothermal energy. Normally constrained to a maximum of 100 hours for each request, APL assistance is in the form of preliminary feasibility, engineering, or economic studies and is not a substitute for detailed design, which is the province of the consulting engineering community. APL efforts can include the following:

1. Counsel on known information concerning geothermal resources in an area and DOE programs that are in process there;
2. Preliminary estimates of the hydrologic properties of geothermal resources as functions of time and usage;
3. Advice on recovering geothermal energy in a specific case (e.g., an engineering feasibility study);
4. Estimates of the life-cycle cost of applying geothermal energy in a specific case;
5. Advice on the legal, institutional, and other requirements for the application of geothermal energy; and
6. Advice on available federal geothermal opportunities or other federal programs that relate to the use of geothermal energy.

DISCUSSION

The technical assistance program provided by DOE through APL and other institutions has been helpful in determining the potential, the method of application, and the approximate cost of developing geothermal energy. It also informs DOE/DGE and the parties involved of the problems the potential user faces from a technical, financial risk, or management point of view. APL (Ref. 1) reviewed (for DOE/DGE) the considerable growth of this effort during the current fiscal year and recommended additional funding and effort to provide timely responses to requests for assistance.

During this reporting period, no new technical assistance projects were initiated. Additional funding for the effort is in process.

Documentation and assistance not previously reported. A paper entitled "Geothermal Technical Assistance - Eastern U.S." was presented at the Geothermal Resources Council's (GRC) Annual Meeting in Salt Lake City, 9-11 Sep 1980. The paper is available in the GRC transactions of the annual meeting (Ref. 2) and in an APL report (Ref. 3).

The analysis of geothermal energy as applied to space heating at the Naval Air Rework Facility at Sewell's Point, Norfolk, Va., has been published as a formal report (Ref. 4).

Lewes, Del. Ebasco Services, Inc., was responsible for assisting the Delaware State Energy Office in preparing a geothermal development proposal for Lewes, Del. In response to a request in June from Ray Scimeka of Ebasco, the Center for Metropolitan Planning and Research (Metro Center) provided assistance in analyzing the proposed project with the GRITS (Geothermal Resource Interactive Temporal Simulation) computer simulation model. The initial analysis modeled a resource characterized by 5000, 6000, and 7500 ft wells, with wellhead temperatures of 120, 140, and 150°F and maximum possible flows of 160, 250, and 350 gal/min. A single industrial user requiring 37.4 billion Btu's per year was modeled. The influence of the utilization factor of the well on the project's discounted average cost was also illustrated. The GRITS analysis was submitted as supporting evidence in Delaware's proposal for support (Ref. 5) under the Eastern Geothermal Drilling Program Solicitation (Ref. 6).

New York State. The New York State Energy Research and Development Authority (NYSERDA) has requested consulting help with the details of the deep well to be drilled at Montezuma, N.Y. We have advised them of deep drilling and testing techniques, costs, and subsurface geologic and hydrologic conditions determined from extensive gas exploratory drilling data. References 7 and 8 document some of these recommendations. In addition, Burton Krakow has requested an analysis of the costs of geothermal energy in the New York State area. This analysis is summarized below.

Metro Center used the computer evaluation model GRITS as an aid in studying the prospective resource. Preliminary sensitivity analyses were performed for several alternative resource, demand, and financial conditions. Alternative resources simulated in the tested scenarios ranged from optimistic 5000 ft wells of 130 and 150°F, to a 4000 ft well at 130°F, to a conservative 3000 ft well at 110°F (all maximum possible flows were 200 gal/min). The hourly temperature distribution for Syracuse was used, along with the optimal design temperature (the temperature at which all heating demand is supplied by the geothermal resource alone, as opposed to the peaking boiler), to simulate five district heating systems. Each was composed entirely of either single-family suburban residences, single-family dense residences, townhouses, garden apartments, or high-rise housing. To examine the effect of alternative fuels for the peaking boiler, oil and gas were specified as the peaking fuels in the scenarios. In addition, a scenario was improvised to compare the geothermal district heating systems with one heated solely by a fossil fuel boiler. Substantial savings were indicated with the use of geothermal water.

Through the end of the third quarter, NYSERDA was continuing its analysis of the results. They will be documented in the next quarter.

Mariculture in North Carolina. At the request (Ref. 9) of James Fletcher of Nags Head, N.C., the North Carolina State Energy Office was contacted to provide assistance to Mr. Fletcher in the preparation of a user-coupled resource confirmation proposal (Ref. 10). Mr. Fletcher raises eels and rockfish and wishes to use geothermal energy to heat the water in which these fish grow.

Kings Bay, Ga. The Trident Submarine Support Base, Kings Bay, Ga., is under construction. The Navy has let a contract to Fosdick, Hilmer, Inc., a consulting engineering company of Cincinnati, Ohio, to design a coal-fired heating

plant. There is interest in assessing the potential of geothermal energy to supply a portion of the base load of this heating plant. Reference 11 suggested that a gradient well be drilled on the Kings Bay site. Reference 12 forwarded information on geothermal energy for base load space heating. The Virginia Polytechnic Institute and State University is drilling a shallow (1000 ft) gradient well at Kings Bay. The data may provide sufficient information to determine if a deeper well is warranted.

New Heat Pump Concept. Mr. Donald Erickson of Energy Concepts Corp. of Annapolis, Md., requested assistance in locating potential users of geothermal energy where the geothermal heat would require a peaking plant to match the desired process heat, for example, an alcohol (ethanol) distillery near a geothermal resource of modest temperature. Conversely, if cooling were required the refrigeration unit could be driven by a geothermal resource with a temperature in excess of 160°F. Energy Concepts Corp. has several proprietary heat-pump designs that it wishes to develop and demonstrate for both of these applications. Mr. Erickson was put in touch with Clifton B. McFarland of DOE/DGE, F. Crestwich of Oak Ridge National Laboratory, and several prospective gasohol distillers who are planning to construct plants in the Delmarva area.

District Heating - Richmond, Ind. The town of Richmond, Ind., (Ref. 13) requested assistance in assessing the potential for space heating of shallow aquifers under the major portions of the town. The town will be informed of the planned HUD district heating study, and discussions with the town will follow upon receipt of additional funding.

Geothermal Loan Guarantee Information. At the request of DOE/DGE, a subcontract is planned with Washington Analytical Service Center of EG&G, Rockville, Md., to inform those requesting counsel what financial assistance is available and, in particular, the details and mechanics of the Geothermal Loan Guarantee Program. This effort will begin in early FY 81.

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GEOHERMAL ENERGY DEVELOPMENT PLANNING AND TECHNICAL ASSISTANCE

\$ 16

Development of Geothermal Energy in the Eastern U. S. ZJ70CQO

Support: DOE/DGE

F. C. Paddison (APL) and S. Kane and H. Shukla (Metro Center)

July-September 1980

GEOHERMAL ENERGY MARKETS ON THE ATLANTIC COASTAL PLAIN – MARKET DEFINITION

A Geothermal Energy Market Study (GEMS) is being performed in four of the six potential geothermal resource areas on the Atlantic Coastal Plain (ACP). The purposes of the study are to (a) identify existing energy requirements for space and water heating and for process heat at temperatures below 250°F, (b) determine the technical feasibility of meeting these energy requirements with the type of geothermal resources expected on the ACP, (c) estimate the cost of geothermal energy for potential applications, and (d) estimate the potential penetration of geothermal energy into the energy markets that are technically and economically attractive. APL is conducting the first two efforts, and the Metro Center is assisting in the latter two efforts – reported elsewhere in this Quarterly Report.

SUMMARY

A report of the energy market for the mid-ACP (Ref. 1) has been completed and will be issued during the next quarter. The areas are shown in Fig. 1.

DISCUSSION

Mid-ACP. Previous Quarterly Reports have summarized the energy market potential for geothermal energy in the mid-ACP. Reference 1 gives the complete results of the study of that area.

Southern ACP. The southern ACP is shown in Fig. 2. The shaded counties are those where the depth of the sedimentary sequence (Ref. 2) and the thermal gradient (Ref. 3) combine to provide an estimated maximum temperature in excess of 90°F.

As part of general demand studies, housing stock data of major cities located in North Carolina, South Carolina, and Georgia were analyzed to determine the range and density of units convertible to geothermal energy.

Residential heating equipment considered to be unconvertible included those with floor, wall, or pipeless furnaces; room heaters with or without flues; fireplaces; stoves; and portable heaters of all types. Figures 3, 4, and 5 describe the distribution of housing units convertible to community heating on the census tract level.

On the average, the percentages of housing units lacking internal heat distribution systems (with prohibitive conversion costs) was typically above 50% and ranged as high as 60 to 70%. Table 1 lists the percentage of convertible housing stock in each of the three southern cities under investigation plus the percentage of convertible units in the two mid-ACP cities (Atlantic City, N.J., and Salisbury, Md.) that were examined in a previous study. The south-

Fig. 1 Areas of completed market survey, mid-Atlantic Coastal Plain. (80-3/66)

Fig. 2 Areas planned for market survey, southern Atlantic Coastal Plain. (80-3/67)

Table 1

Percentage of housing stock convertible to geothermal energy in five Atlantic Coastal Plain cities.

City	Housing convertible to geothermal (%)
Atlantic City, N.J.	88
Salisbury, Md.	65
Wilmington, Del.	50
Charleston, S.C.	40
Savannah, Ga.	30

ernmost cities studies were found to have the least number of households convertible to a geothermal community heating system (Ref. 4).

Fig. 3 Percentage of convertible housing versus number of census tracts in three southeastern cities. (80-3/68)

Fig. 4 Density of demand for residential space heating in Savannah, Ga. (80-3/69)

Space heating density maps for each of the three cities were generated. Total energy demand density maps provide information on the size of the potential space heating market and its geographical location. Figure 4 shows the density of demand for residential space heating in Savannah, Ga. In order to be able to assess the density of housing convertible to geothermal energy, a second series of space heating density maps were generated for each of the three southeastern cities. Figure 5 shows the space heating density map for Savannah. It includes only those units convertible to a community heating system.

Fig. 5 Density of demand for residential space heating (convertible housing stock only) in Savannah, Ga. (80-3/70)

Weather data for the southeastern cities were used in GRITS to estimate the effect of lower heating loads on the economic viability of community heating systems in this region. The housing distribution of each census tract, the percentage of the housing market that geothermal could penetrate (i.e., market saturation in GRITS, percentage of convertible housing in this study) for each census tract, and the optimal design temperature for the hybrid geothermal system with a fossil fuel peaking boiler were all specified in GRITS. The discounted average costs (DAC) per million Btu of geothermal energy and the net present value (NPV) of revenues minus cost were generated for each of three cities. The further south a city was located geographically, the higher the cost of supplying a customer with geothermal energy and the lower the return to the utility providing the geothermal energy. This trend is indicative of the combined impact of conversion costs for most homes and the lower heating load.

FUTURE PLANS

The cost of supplying convertible housing in the three southeastern cities with geothermal energy will be compared with the prices of traditional fuels to determine the economic feasibility of geothermal community heating systems in the southeast. The results will be published during the next quarter. The detailed survey of other energy markets in the southern ACP will be initiated in the next quarter.

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GEOHERMAL ENERGY DEVELOPMENT PLANNING AND TECHNICAL ASSISTANCE § 17

Development of Geothermal Energy in the Eastern

U. S. ZJ70CQO

Support: DOE/DGE

S. Kane, P. Kroll, and B. Nilo (Metro Center)

July-September 1980

GEOHERMAL ENERGY MARKETS ON THE ATLANTIC COASTAL PLAIN - ECONOMIC MODELING

A computer model called GRITS (Geothermal Resource Interactive Temporal Simulation) was developed to estimate costs of geothermal energy for various applications and for various resource, market, and financial conditions (Ref.

1). The discounted revenue and cost streams, both of which are needed to determine the net present value of the system, are estimated. The GRITS model evolved from the simpler, less sophisticated model called GREES (Geothermal Resource Economic Evaluation System) (Ref. 2).

GRITS (Ref. 3) is used to make preliminary economic evaluations of community heating systems or process heating applications. We are attempting to identify parameters that exhibit ranges of sharply increasing costs and are therefore crucial to the economic viability of specific projects.

SUMMARY

The current work with the GRITS model includes extensive sensitivity analysis of the impact of resource, demand, and financial conditions on the cost of geothermal energy. Results of this analysis will be included in a report on the economics of direct applications of low to moderate temperature geothermal resources.

Fig. 1 GRITS: geothermal resource interactive simulation model.(80-3/71)

Fig. 2 Discounted average costs as a function of transport distance. (80-3/72)

Fig. 3 Discounted average cost as a function of well cost. (80-3/73)

DISCUSSION

The GRITS model was developed to assist policy makers, utilities, potential investors, and persons interested in the economic feasibility of unconventional energy sources in examining the impact of a wide range of conditions on calculated costs. GRITS enables an analyst to vary many resource, demand, and financial con-

ditions in a temporal simulation of the life of a geothermal project. The program contains 44 parameters that may be varied. A schematic diagram indicating the conceptual structure of GRITS and the conditions that may be selected by the model user to depict the geothermal system is presented in Fig. 1.

Given a set of resource conditions, GRITS determines the amount of geothermal energy that can be supplied by the resource and sizes the system accordingly; i.e., it brings on line as much demand (for example, households in the residential section) as can be supplied. Also, residential/commercial heating demands or industrial process heat scenarios can be modeled.

GRITS is being refined continuously as new data become available. Research into the role that tax incentives play in the economic viability of moderate temperature geothermal resources is under way. However, since no major additional modifications in GRITS are being planned, the functional relationships between parameters and the cost of energy have been investigated systematically. The results will be published in a companion volume to the GRITS report just released.

An example of the sensitivity analysis is provided in Fig. 2. Discounted average costs are plotted as a function of the distance geothermal energy is transported from the wellhead to the user's site for a process heating application of two hypothetical reservoirs. As shown in Fig. 2, discounted average costs for higher quality resources do not rise as rapidly as they do for poorer quality resources for which there is sensitivity to even minor increases in transport distance. Such information is useful in assessing the impact of transport distance on costs and points out the need for studying land use and ownership patterns that cause siting of geothermal wells that are some distance from the users.

A second example is shown in Fig. 3 where discounted average costs are plotted as a function of average per-foot cost of a well. The costs are those that are assumed for an industrial user having a production and a reinjection well of equal depth for two geothermal resources of different quality.

FUTURE PLANS

The initial report on the sensitivity analysis will be issued during the next quarter.

An extension of the initial sensitivity analysis is planned where the default value of per-foot well costs will be increased to \$75/ft.

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GEOHERMAL ENERGY DEVELOPMENT PLANNING AND TECHNICAL ASSISTANCE § 18

Development of Geothermal Energy in the Eastern U. S. ZJ70CQO

Support: DOE/DGE

P. Kroll and S. Kane (Metro Center) and K. Yu (APL)
July-September 1980

ECONOMIC MODELING OF GEO-THERMAL PROJECTS - DISCUSSION OF TOOLS AVAILABLE AND EXAMPLES OF THEIR USE

A series of computer programs has been developed at APL and the Metro Center to refine the methods for making economic analyses of potential geothermal resource development projects. The initial static model GREES (Ref. 1) was superseded by GRITS (Geothermal Resource Interactive Temporal Simulation Model) (Ref. 2), a simulation program allowing time-variant conditions. Two new models, DSM (Demand Specified Model for Direct Applications of Geothermal Energy) (Ref. 3) and BIGMAC (Basic Interactive Geothermal Model with Aquifer Characterization) (Ref. 4), have been drawn from GRITS for specific analysis applications. A desk-calculator program to calculate the payback period for conversion from displaced fossil fuel to geothermal energy is documented in Ref. 5. The last four models are all in use in on-going analyses, and several models have already been made available for cost analysis by outside users.

SUMMARY

The temporal simulation model, GRITS, was used in the third quarter of 1980 to determine the sensitivity of a geothermal system's costs and revenues to changes in resource, demand, and financial conditions. In addition, as a service to the states of Delaware and New York, the GRITS program was used to provide estimated costs of prospective commercial and/or district heating. Two additional computer models (DSM and BIGMAC) derived from the basic structure of GRITS were developed for use with related subsets of this type of analysis. DSM was designed to meet two needs that were identified through use of GRITS: first, DSM permits a user having a specified level of heating demand to make an economic analysis of a geothermal project and second, DSM is simpler to run for someone who is unfamiliar with the more detailed structure of GRITS. BIGMAC is very similar to DSM but incorporates aquifer modeling to estimate more accurately the consequences that an assumed geothermal water withdrawal scenario has on pumping energy. Finally, a small programmable calculator program was designed to determine the payback of capital costs due to conversion from the displaced fossil fuel to geothermal energy; it is a useful preliminary to more extensive investigations that use the other programs such as GRITS, mentioned above.

DISCUSSION

GRITS. GRITS provides accounting of geothermal space heating for single-building or

district heating or for industrial process heat. The methodology provides for the effects changing resource and demand conditions have on costs over the lifetime of a geothermal project. GRITS calculates both the revenue and cost streams for each year of the project and from these it gives the net present value for the analysis of the system's economic viability.

The GRITS computer model (Ref. 2) has undergone several months of testing and analysis in its latest version, and efforts are under way to extend its availability to outside users. GRITS enables an analyst to vary many resource, demand, and financial conditions to simulate the life of a geothermal project. The model's flexibility, the ease with which it can be used as an interactive computer program, and its combined economic and engineering detail, make it useful in analyzing particular resource development projects and in performing sensitivity analyses of chosen parameters. To illustrate the utility of GRITS, Fig. 1 shows the average cost of one million Btu versus geothermal well flow rate for a resource temperature of 130°F. The residential sector assumes the following mix of housing stock: 3% single family suburban, 6% single family dense, 14% townhouses, 23% garden apartments, and 54% high rise apartments. The number of degree-days is comparable to Atlantic City weather.

Figure 2 illustrates the average cost of one million Btu used for residential space heating versus geothermal well flow rate. The mix of housing stock is the same as for Fig. 1, but two different resource temperatures are shown. When this version of the model is completed, an exhaustive sensitivity analysis of varied resource, demand, and financial conditions will have been done. The results of that analysis will be published in a forthcoming report. Several runs of the GRITS model have been provided to Ebasco Services, Inc. for their use in preparing a geothermal well development proposal for the state of Delaware and to the New York Energy Research and Development Authority for its use in analyzing a partial resource development near Syracuse. Also, inquiries about GRITS have been received from abroad. Additional re-

Fig. 1 GRITS analysis of average cost versus flow rate for residential sectors with different resource temperatures. (80-3/75)

Fig. 2 GRITS analysis of average cost versus flow rate for residential sectors with different resource temperatures. (80-3/75)

quests for analyses using GRITS are expected from other potential geothermal users.

For those familiar with the GRITS model, it became apparent during its developmental stages that the detail provided by the program allowed comprehensive specification of alternative development scenarios. However, two limitations arose as possible inhibiting factors: for those unfamiliar with the model, the attempt to master the many optional parameter specifications could become unwieldy; and second, for user applications where the demand is given, GRITS would require the user to test several scenarios in order to attain that specified demand. As a result, DSM (Ref. 3) was derived from GRITS.

DSM. This modified version of the commercial routine of GRITS is simplified and is used to analyze a system designed to meet a given heating demand at the design temperature, whereas GRITS assumes that enough demand for the geothermal energy exists to consume whatever geothermal energy the resource is able to supply. An example of an application suitable for analysis by DSM is a geothermal well that can be used to heat a limited number of buildings on an isolated university campus or agricultural community. The financial calculations are the same as those in GRITS, except that the financial measure of the present value of the project is replaced by the measure of the payback period. The payback period is the time in which the initial capital investment is paid back by savings in operating expenses due to conversion to a geothermal system.

The primary emphasis in the Metro Center and APL computer modeling effort, as reflected in GRITS and DSM, has concentrated on the economic analytical point of view, providing sufficient engineering accuracy for validity; therefore, the models have developed a relatively high level of sophistication for such purposes. However, since pumping energy (a major operating cost component of a geothermal system) depends largely on the geologic and hydrologic characteristics of the resource being extracted, as well as on the pumping operation of the well, APL has developed a model of the aquifer's influence on pumping for incorporation into the economic analysis programs (Refs. 4 through 6).

BIGMAC. This model is a modified version of DSM. It incorporates the series of relationships discussed above, taking into account the

Fig. 3 Example of plotted capital recovery period versus oil price escalation rate from program listing. (80-3/76)

transmissivity and storage coefficient for an aquifer whose characteristics are known or can be estimated. Also considered is whether the pumping cycle is continuous, varies semiannually or daily, or is of the type resulting from space heating. This aquifer modeling effort was used to modify a version of DSM, resulting in the development of the third new computer model, BIGMAC (Ref. 4).

Program to Calculate Geothermal Capital Recovery Period. A desk calculator program for estimating the capital recovery period for a geothermal space heating system was developed at APL for use with the Hewlett-Packard 97 calculator. The program can also be adapted to the Texas Instrument 59 calculator for use with the PC-100 printer.

The program was developed to provide a simple economic model that could be used in geothermal technical-assistance projects. The program output is in the form of a listing that shows how many years are required to pay off the cost of a geothermal space heating system (total capital investment) as a function of incremented grant function and the annual oil price escalation rate (Refs. 7 and 8). These data can then be plotted to show the trends of the incremental functions, as shown in Fig. 3.

The pay-off strategy used in the program is that the debt is paid off by the net fuel savings alone as a result of using the geothermal system. This program was used in several APL technical assistance reports and has proved to be most valuable.

FUTURE PLANS

GRITS and DSM are considered to be at the end of their current development stages, and efforts are under way to encourage outside use of the programs and their results. Sample results have been provided in response to domestic and foreign inquiries and have been used in assisting the State of Delaware in preparing a resource-development proposal. Detailed documentation of DSM is to be published during the next quarter. BIGMAC has undergone its initial calibration and is expected to be used during the next quarter to analyze the sensitivity of the economics of a geothermal project's pumping requirements to its aquifer and use characteristics. A report on this analysis is also expected to be published during the next quarter.

REFERENCES

1. R. Weissbrod, W. F. Barron, P. Kroll and W. J. Toth, "Economic Evaluation Model for Direct Use of Moderate Temperature (Up to 250°F) Geothermal Resources in the Northern Atlantic Coastal Plain," JHU/APL GEMS-003/QM-79-124, Jun 1979.
2. W. F. Barron, P. Kroll, R. Weissbrod, and W. J. Toth, "GRITS: A Computer Program for the Economic Evaluation of Direct Applications of Geothermal Energy," JHU/APL GEMS-008/QM-80-077, Jun 1980.
3. P. Kroll and W. Barron, "DSM, The Demand Specified Model for Direct Applications of Geothermal Energy: A User's Manual," JHU/Metro Center, 27 May 1980.
4. P. Kroll and W. Barron, "BIGMAC, Basic Interactive Geothermal Model with Aquifer Characterization: A User's Manual," JHU/Metro Center, 17 Jun 1980.
5. K. Yu, "A Drawdown Model for Inclusion in GRX," memo, 1980.
6. P. Kroll, "Pumping Energy Equation," memo to K. Yu, 7 May 1980.
7. K. Yu, "Capital Recovery Period," JHU/APL QM-80-43, Mar 1980.
8. K. Yu, and R. von Briesen, "A Program for Capital Recovery Assessment for the H-P-97 and Other Calculators," JHU/APL QM-80-125, Aug 1980.

 

GEOHERMAL ENERGY DEVELOPMENT PLANNING AND TECHNICAL ASSISTANCE § 19

Development of Geothermal Energy in the Eastern

U. S. ZJ70CQO

Support: DOE/DGE

J. E. Tillman, C. J. Leffel, Jr., F. C. Paddison, and
R. F. Meier (APL), and S. Kane, and B. Nilo
(Metro Center)

July-September 1980

COMMENTS ON LIMITED TASKS

FORMATION OF STATE TEAMS

The objectives and description of the geothermal prospectus for the Delmarva Peninsula, as originally written by APL, were discussed in Ref. 1. The intent is to have the prospectus completed, state-specific, by the three states of the Delmarva Peninsula (Delaware, Maryland, and Virginia). Each state would create an organization to complete its prospectus, familiarize itself with the problems of developing geothermal energy, and add the state-specific information not included in the generic prospectus written by APL. To accomplish this, with federal assistance, each state must submit a proposal to DOE. DOE has indicated a willingness to support the state teams over a useful period if viable teams can be organized (Ref. 2).

To date, only Delaware has submitted such a proposal. The Delaware proposal has been accepted by DOE and a member of the State Energy Office assigned the responsibility of organizing the state team and completing the prospectus. Emily Perrone, a member of the Delaware State Energy Office, attended a meeting at APL on 2 September 1980 to discuss (among other geothermal problems) the completion of the prospectus.

In Virginia, J. Johanson of the Office of Emergency and Energy Services held a meeting on 3 July 1980 to discuss, with other state agencies, the legislative and administrative issues associated with the development of geothermal energy. One of the consequences of this meeting (Ref. 3) was that the Division of Mineral Resources, in cooperation with the Virginia Polytechnic Institute and State University, will prepare a proposal to be submitted to DOE to fund the Virginia Geothermal Prospectus. This prospectus would examine the economics and resources for geothermal energy and serve as a developer's guide book.

As reported in Ref. 2, in Maryland the responsibility for preparing a proposal to DOE for work on the prospectus has been assigned to the Conservation Chief of the Maryland Energy Office. Because of personnel changes, Maryland's effort has been delayed.

REFERENCES

1. Section 16, Quarterly Report, Oct-Dec 1979, JHU/APL EQR/79-4.
2. Section 24, Quarterly Report, Apr-Jun 1980, JHU/APL EQR/80-2.
3. "Geothermal Energy Workshop in Virginia," JHU/APL QM-80-143, 10 Sep 1980.

AID TO NATIONAL CONFERENCE OF STATE LEGISLATURES (NCSL) GEOHERMAL LEGISLATIVE WORKSHOPS

Metro Center and APL have continued to lend assistance to NCSL in a number of legislative workshops held during the past few months. Currently the Maryland and Virginia State Legislatures are in the process of formulating and/or reexamining geothermal legislation. The Subcommittee of the Virginia Coal and Energy Commission held meetings beginning on 3 July 1980 to identify legislative and administrative issues associated with geothermal resources that would pertain directly to the Commonwealth. The general position of the subcommittee was presented at a meeting on 9 September 1980. The major suggestions put forth by the subcommittee include mandatory reinjection of geothermal brine, differentiation between geothermal energy and ground water heat pumps as a resource, preference for private ownership of the resource, and definition of geothermal energy as a unique resource. Metro Center and APL informed the Committee of the technical and economic implications of the various policy options.

A meeting of the Special Joint Committee on Energy of the Maryland State Legislature is planned for 30 September 1980. The meeting will address the problems of restructuring the Geothermal Resources Act of 1978.

State of Maryland. The Maryland Geothermal Resources Act (Senate Bill 1154) became law 1 July 1978. The act has been criticized on the grounds that the question of ownership is left ambiguous. On 5 May 1980, the State Special Joint Legislative Committee on Energy met with NCSL to discuss amendments to the act. Another meeting was held on 2 July 1980; it was attended by representatives of NCSL and APL (Ref. 1). The details of the latter meeting are included in Ref. 1. In brief, APL, with much support, argued for a clear statement in the law to place ownership in the public domain. The question of a special status for geothermal resources was discussed without resolution. A meeting with NCSL and APL is scheduled by the Legislative Special Joint Energy Committee for 30 September 1980. At that time, NCSL will attempt to clarify the options that the State has for amending the Geothermal Resources Act.

State of Delaware. The Legislature of Delaware passed "The Geothermal Resources Act of 1970" (Senate Bill 469). This act, written with considerable assistance from NCSL and APL, provided for state title to geothermal resources, with development rights remaining with the individual developers. It also provided the legal/regulatory framework to guide geothermal development in the State. The Delaware Geothermal Resources Act was vetoed by the Governor in July 1980 on the grounds that it imposed "a new regulatory maze and layer of red tape," thus hindering geothermal development, and that "it jeopardized the legitimate property rights of Delaware landowners" (Ref. 2). Thus, for the present time, geothermal energy development in Delaware will proceed without the assistance (or hindrance) of Senate Bill 469.

State of Virginia. On 9 September 1980, J. E. Tillman of APL and B. Nilo of Metro Center participated in a workshop convened by S. Valentine of NCSL with the Geothermal Subcommittee of

the Virginia Commission on Coal and Energy (Refs. 3 and 4). In addition to JHU, technical experts from the U.S. Geological Survey and Virginia Polytechnic Institute and State University were present. Four of the six members of the subcommittee were present, with L. Parker, Jr., presiding. The purpose of the meeting was to initiate draft legislation for a geothermal law to be presented to a full commission in November and to the legislature in January.

During the meeting, J. Johansen of the Office of Emergency and Energy Services announced that he had recently held several workshops to identify legislative and administrative issues associated with geothermal energy. The position and suggestions resulting from these meetings are given in Ref. 4. Since many of the attendees at the meeting and the majority of the members on the subcommittee were new, S. Valentine touched on many aspects of geothermal energy in order to provide them with background information.

The representatives of JHU participated in response to questions about the resource and economics. JHU will assist in the next meeting, slated for the end of October 1980, to present clearly all the options available to the State with their pros and cons.

In the matter of ownership, the purpose of legislation must be made clear. If it is to encourage the economic and environmentally acceptable development of an energy resource indigenous to the State of Virginia, the law should attempt to remove legal deterrents. The nonrestricted regional nature of the resource and its marginal economic value suggest that the citizens of the state have little to gain from its private ownership. If the resource is placed in the public domain, the developer does not face the litigation nightmare related to its use. In either case of ownership, the landowner still receives financial benefits for surface rights needed for access to the resource. These benefits may far exceed any percentage profit gained from use of the resource.

With regard to a definition of the resource, the committee members are leaning toward establishing a depth range and toward excluding water-referenced heat pumps from the legislation. This is probably not practical in Virginia since geothermal resources exist at many depths as well as at the surface. A definition based on the use of the resource may be more appropriate. However, including water-referenced heat pumps in the definition requires a priority in areas where there are competing demands on a limited water supply, such as the area near Virginia Beach. The priority will have to be established on a local basis by the Water Control Board and probably belongs in the rules and regulations.

NCSL "Guidebook to Ground Water Heat Pumps." In May 1980, NCSL published the draft of a guidebook on groundwater heat pumps. It was designed to inform state legislators of the technical aspects and possible legal problem presented by groundwater heat pumps. The paper was submitted to APL for comment and suggestions. The APL suggestions for corrections or additions are contained in Ref. 5 and are largely technical in nature. It is emphasized that legislators should be made familiar with the technical and economic factors in groundwater heat pumps to the extent that the water resource and disposal problem peculiar to these devices be clearly delineated (Ref. 3).

REFERENCES

1. "Legislative Workshop in Annapolis, July 2, 1980," memo to F. C. Paddison from J. G. Cherim, Metro Center, 3 Jul 1980.
2. Pierre S. duPont, Governor, letter to the Senate of the 130th General Assembly of the State of Delaware, Jul 1980.
3. "Geothermal Energy Workshop in Virginia," JHU/APL QM-80-143, 10 Sep 1980.
4. B. D. Nilo, "Virginia Coal and Energy Commission Subcommittee Meeting," memo, 15 Sep 1980.
5. "Suggestions Relating to the National Conference of State Legislators Pamphlet on Heat Pumps," JHU/APL CQO-2925, 26 Aug 1980.

MARKET SURVEY DATA AND MARKET PENETRATION ANALYSIS.

The Technical Research and Analysis Corporation of Alexandria, Va., (TRAC) under contract to DOE/DGE, is using a diffusion model to assess long-term geothermal development. JHU/APL market survey data and reports on the analysis of market penetration in the eastern United States were forwarded to TRAC (Ref. 1). In the next quarter, a meeting is planned to discuss the APL data and the TRAC model.

REFERENCE

1. "Forwarding of Reports," JHU/APL Lett. CQO-2922, 21 Aug 1980.

SUPPORT OF INDUSTRIALIZATION TEAMS

DOE/DGE is organizing a team of specialists to meet with and advise the food industry on the potential of geothermal energy as applied to their production processes. APL will contribute to the team as necessary. Reference 1 forwarded a report of the APL technical assistance program and the economic analysis tools that are available.

REFERENCE

1. "Narrative Description of Technical Assistance Program Available at APL," JHU/APL Lett. CQO-2934, 16 Sep 1980.

SUPPORT OF HUD DISTRICT HEAT TEAMS

On 13 August 1980, a meeting was convened by Eric Peterson (DOE/DGE) to organize a District Heating Product Team (Ref. 1). In order to encourage study of the potential for community heating systems, HUD is sending solicitations to a select group of towns. They are scheduled to be mailed early in the fall of 1980. In Phase I, HUD will allot each town funds for preliminary studies of district heating systems. It is assumed that the DOE/DGE District Heating Product Team will continue to assist selected communities through Phase II. Selected proposals dealing with geothermal energy will also have the assistance of the team.

A study designed to evaluate and compare all geothermal models will be undertaken during 1981 (Ref. 2). The State of Oregon will examine

the models for overall usefulness and will make recommendations for future funding.

REFERENCES

1. "USDOE/DGE District Heating Product Team," Rockwell International ETEC, 23 Sep 1980.
2. "Data for Hopkins Cost Models," JHU/APL Lett. CQO-2939, 18 Sep 1980.

GEOTHERMAL PROGRESS MONITOR

The Division of Geothermal Resources Management (DGRM) in DOE has instituted a periodic reporting system to inform appropriate agencies and persons of changes in activities leading to the commercialization of geothermal energy. APL personnel participated in the planning of this system, known as the Geothermal Progress Monitor, and regularly contribute geothermal material for the eastern United States. Reference 1 is a compilation of data for the third Progress Monitor report.

REFERENCE

1. "Geothermal Program Monitor Report No. 3," JHU/APL Lett. CQO-2910, 18 Jul 1980.

STATE-BY-STATE FACT SHEETS

Reference 1 forwarded the original state-by-state fact sheets to recipients in the eastern United States. These sheets provide a geologic overview of each state and summarize state energy resources and usage, the status of geothermal energy studies and development, and geothermal contacts within each state. They are intended

as a convenient quick reference. The book which contains most of the states is being enlarged to include them all and is to be reissued the next quarter.

REFERENCE

1. "State Geothermal Fact Sheets," JHU/APL Lett. CQO-2406, 29 Mar 1979.

THE WASHINGTON, D.C., OGLE COMMITTEE MEETING

The Ogle Committee, which coordinates the geothermal effort of the National laboratories, met in Washington, D.C., on 6-8 August 1980. The APL representative presented a summary of effort in the eastern United States.

MEETING WITH OAK RIDGE NATIONAL LABORATORY

On 13 August 1980, F. C. Paddison met with F. Crestwich of the Oak Ridge National Laboratory to discuss the effort of APL for the commercialization of geothermal energy for DOE/DGE and to suggest the carryover of some of those efforts to the ground-coupled or water-referenced heat pumps. The meeting was arranged through the office of John Ryan of DOE's Office of Conservation and Solar and D. B. Lombard of DOE/DGE. A subsequent meeting was held at APL on 9 September 1980 to discuss in greater detail areas of common interest.

 

SSH POWER IN THE SOUTHEASTERN U.S., DRAFT OF COE REGIONAL REPORT

The National Hydropower Study, a computerized program of the U.S. Army Corps of Engineers (COE), is designed to estimate the hydroelectric potential of the United States site-by-site. During the latter part of April 1980, APL received from the Corps' South Atlantic Division (Atlanta, Ga.) complete printouts of the current computer studies for 40 hydroelectric sites in North Carolina, South Carolina, and Georgia. In late August 1980, APL also received from the same source, a draft copy of the Corps' report on hydroelectric power resources for the region covered by the Southeastern Electric Reliability Council (SERC). As requested by the Corps, APL has reviewed and returned its comments on this draft report.

DISCUSSION

The National Hydropower Study, Form 2 (NHSF2), performed by COE for SERC, was discussed in a previous Quarterly Report (Ref. 1). As described in Ref. 1, the limited number of NHSF2 printouts supplied to APL has been used to calculate the capital costs of hydroelectric installations. These costs have been used to investigate the feasibility of installing hydroelectric power by nonfederal developers at existing dam sites in North Carolina, South Carolina, and Georgia (see article by R. Bennett elsewhere in this Quarterly Report).

The draft version of the COE report on NHS was received by APL for review and comment on 25 August 1980 (Ref. 2). Except for the region of the Tennessee Valley Administration (not included in the APL studies), the SERC region essentially coincides with the region covered by the APL Southeastern U.S. Small-Scale Hydro (SSH) Study. Reference 2 describes the method of the COE selection of sites and lists and ranks the sites that the COE concludes are feasible for development. Those sites are the conclusions reached (as of August 1980) as a result of the screening process that has been performed on NHSF2. Included in Ref. 2 are the existing sites with hydroelectric power whose energy output can be expanded by additional capacity, existing dams with no existing capacity but where hydroelectric power could be installed, and "underdeveloped" sites, i.e., sites without dams but which are reasonable to develop.

Omitting new dam construction (which is of no interest to the APL study) for the three states of North Carolina, South Carolina, and Georgia, which are the object of the APL financial analysis, Ref. 2 lists the following number of sites:

	Sites with power, to be incremented	Sites without power	Total
North Carolina	11	22	33
South Carolina	17	7	24
Georgia	12	5	17

Reference 2 eliminated all sites with a recommended capacity below 1 MW and which have serious environmental, social, or institutional impediments.

The appendixes of Ref. 2 list the site number, owner, location, average steam flow, dam height, existing capacity and energy production (if any), and the suggested calculated incremental capacity and energy production. The annual cost of installing and operating the incremental capacity is given; from the estimated annual electricity produced, the cost per megawatt-hour of the incremental electricity is computed. The annual cost for the installation is the COE cost for that installation that maximizes the difference between annual cost and annual benefit as calculated on NHSF2. Aside from the information stated above, no other financial information is contained in Ref. 2, although the lists do contain a ranking based on economic factors alone, one based on social and environmental factors, and a composite ranking. The electricity produced at operating sites, at existing sites whose production is incremented, and at undeveloped sites is summarized below.

	Existing production (GWh)	Incremental production (GWh)	Potential at undeveloped sites (GWh)
N.C.	414	331.9	4192
S.C.	513	65.2	2196
Ga.	392	99.2	1676

The incremental power at existing dams increases hydroelectricity production by 35%. The potential for electricity production at nonexisting dams is an order of magnitude greater. In the three states discussed here, the present contribution of hydroelectricity to the total electricity consumption is from 5 to 7%.

APL comments on the COE draft report are given in Ref. 3. The COE Charter for the National Hydroelectric Power Study is very broad - to estimate the total hydroelectric potential of the United States. Therefore, as a first cut, the COE decision to eliminate all sites below 1 MW capacity is reasonable. The site list of Ref. 2 is heavily biased, as it must be, toward sites owned by private utilities and government entities, particularly COE. As Ref. 3 points out, it

would be helpful for the nonfederal developer if Ref. 2 and NHSF2 explicitly stated the capital cost of a hydroelectric development for several installed capacities at a given site instead of only listing the annual operating cost as calculated by COE economics for the optimum power installation that NHSF2 selects. Further, Ref. 2 does not contain an explicit estimate of the benefits to be realized for the given power installation, nor does it describe in detail the schedule by which the benefits were calculated. For the purposes of this report; these quantities are not necessary since the costs of producing electricity are given. This makes it possible to give a consistent ranking of the feasibility of the sites. However, in NHSF2 the benefit schedule is used to select the optimum power installation. This information, when available (and if available for installations below 1 MW), will be of great value to any potential developer of an existing dam site.

REFERENCES

1. Section 26, Quarterly Report, Jan-Mar 1980, JHU/APL EQR/80-1.
2. "National Hydroelectric Power Resources Study, Regional Report, Vol. XVI," draft report, U.S. Army Corps of Engineers, South Atlantic Division, Atlanta, Ga.
3. "Review of the Draft Version of National Hydroelectric Power Resources Study, Regional Report Volume XVI," JHU/APL Lett. CQO-2937, 17 Sep 1980.

OPERATIONAL RESEARCH, HYDROELECTRIC POWER DEVELOPMENT

\$21

Small Dam Hydroelectric Retrofit Program ZP30CQO

Support: DOE/RA

R. Bennett (Metro Center)

July-September 1980

SYNOPSIS OF ECONOMIC ANALYSIS OF DEVELOPMENT IN NORTH CAROLINA, SOUTH CAROLINA, AND GEORGIA

The Metro Center has conducted a study of the economic, institutional, and environmental factors affecting potential hydroelectric development at existing dams in North Carolina, South Carolina, and Georgia. The economic analysis will review the critical factors affecting small-scale hydroelectric (SSH) energy supply in the near term in the three-state area; these factors are type of developer, regional energy costs, and capital costs. The effectiveness of various subsidies to SSH sites will also be discussed.

DISCUSSION

The economic analysis that follows is based on cost and electricity production estimates supplied by the U.S. Army Corps of Engineers (COE) for 22 existing dams. Using the COE financial parameters, COE estimates the total economically feasible potential capacity at these sites to be 85 MW. Using economics applied to only the nonfederal sector, this study shows that these 22 dams would be developed to the fullest extent by municipalities and public utilities. Under energy-price projections for base prices, municipal and public developers could produce in 1983 145 GWh (from 37 MW of installed capacity) per year at the median municipal price. Electric cooperatives, including both rural electric cooperatives and the newer generation and transmission cooperatives, could produce 99 GWh per year (22 MW capacity), private entrepreneurs could produce 24.8 GWh per year (6 MW capacity), and investor-owned utilities could produce 3.5 GWh per year (0.4 MW). For these estimates, the income for each class of developer is based on the median 1983 price. (The median price for each developer is based on his particular avoided energy and capacity costs or the avoided costs of the electric supplier to whom he would sell the energy. Consequently, the median prices of municipalities and electric cooperatives are based on avoided wholesale energy costs of 2.5¢ and 2.6¢/kWh in 1983 (1979 dollars). The median price to private entrepreneurs is the median utility running rate of 2.2¢/kWh plus an explicit capacity benefit of \$55 per firm kilowatt per year. Investor-owned utilities would earn project benefits equal to their avoided average generation cost (1.8¢/kWh).) The stated amounts of energy and capacity assume that all dam sites are developed or considered for development by the particular developer type, regardless of actual ownership. Therefore, under expected 1983 conditions, private entrepreneurs and investor-owned utilities are able to develop very little SSH capacity.

Project benefits to private SSH developers in the three-state area equal or exceed the project benefits to municipalities and electric cooperatives, but private developers' higher capital cost, greater tax liability, and more stringent financial feasibility requirements

preclude their developing most of these. Since the sites represent the middle size range of SSH sites (the range most likely to be developed) private entrepreneur activity in SSH in the South Atlantic area may continue to be minimal in the absence of subsidies. Federal Energy Regulatory Commission (FERC) licensing activity in 1980 shows that most prospective developers of SSH sites in the three states are municipalities, public entities, and electric cooperatives (Ref. 1). Investor-owned utilities, on the other hand, have somewhat cheaper debt capital and less rigorous financial feasibility requirements for small investments than do small private developers, but their use of average generation costs to represent project energy benefits and their discounting of any capacity benefit from such small generation units exclude most sites from their consideration.

Low energy costs in the South Atlantic region relative to the national average (Ref. 2) play a major role in holding back regional development of SSH sites, especially by the private sector. (Regional end-use energy price differentials prevailing in July through September 1979 show that the cost of electricity in the less urbanized South is 88% of the national average. In the highly urbanized South, it was 95% of the national average. The less-urbanized Northeast had electricity prices very close to the national average.) By contrast, the energy supply from the same sites at energy prices prevailing in the mid-Atlantic region would be about 100% greater for municipal and cooperative developers, 370% greater for private entrepreneurs, and roughly 500% greater for investor-owned utilities. In general, the currently expanding SSH energy supply in the South Atlantic area is relatively elastic with respect to price. In other words, increases in the projected 1983 price would produce more than proportionate increases in the supply of SSH energy.

Modest real rates of increase in regional fuel costs, and therefore in SSH project benefits, have been assumed in this economic analysis. The dominance of coal and nuclear fuel over oil in the area's fuel mix should lead to smaller increases in real electric energy costs than those in the mid-Atlantic region.

The COE's capital cost estimates for the 22 sites incorporate a 20% downward adjustment to reflect lower regional construction costs. If these costs were at a level that is higher than the national average, the energy supply from those developer types with significant amounts of supply in the base case at 1983 median prices would drop sharply: approximately 40% for municipal and other public developers and 30% for electric cooperatives.

In Table 1, comparisons are made among developer types at 1983 median prices to summarize the effectiveness of subsidies to SSH. The total energy supply, the absolute changes in supply, the relative changes in supply, and the costs per barrel of oil saved by the subsidy are compared for all four developer types and for a given subsidy.

In general for all developer types, the subsidy measures included in the economic analysis yield more than adequate returns to justify their costs. The costs per barrel of oil saved are well below the April 1980 price of imported oil (\$30.71 in 1979 dollars) and are even below the average price of No. 6 residual fuel oil sold to utilities and industry (\$23.21 in 1979 dollars) (Ref. 3).

The relatively elastic supply of SSH energy and the perfectly elastic demand result in the large output effects that make these subsidies so cost effective. The currently low supply of SSH energy leaves almost all the potential in the region still unexploited and explains the elastic supply.

Table 1

The effectiveness of subsidies to SSH.

1. Subsidy programs available to public and private developers:

• Subsidization of capital costs through direct grants

	30% of capital cost	50% of capital cost
Largest total supply	Municipal (217 GWh/yr; 69 MW)	Municipal (233 GWh/yr; 80 MW)
Largest absolute change	Municipal (75 GWh/yr)	Elec. coop. (124 GWh/yr)
Largest relative change	IOU* (1537%)	IOU (2320%)
Lowest subsidy cost per barrel oil saved (1979 \$)	IOU (\$1.28)	IOU (\$2.31)

• Price subsidy (over and above 1983 median price of each developer)

	4 mills	10 mills
Largest total	Municipal (201 GWh/yr; 61 MW)	Municipal (226 GWh/yr; 76 MW)
Largest absolute change	Municipal (84 GWh/yr)	Elec. coop. (107 GWh/yr)
Largest relative change	IOU (1136%)	IOU (2546%)
Lowest subsidy cost per barrel oil saved (1979 \$)	IOU (\$4.57)	IOU (\$6.27)

2. Subsidy programs applicable to the private sector:

	• Property tax exemption	• 7% loan program
Largest total	Private entrepreneur (53 GWh/yr; 11.5 MW)	Private entrepreneur (25.7 GWh/yr; 6 MW)
Largest absolute change	Private entrepreneur (28 GWh/yr)	Private entrepreneur (8 GWh/yr)
Largest relative change	IOU (423%)	Private entrepreneur (43%)
Lowest subsidy cost per barrel oil saved (1979 \$)	IOU (\$2.13)	Private entrepreneur (\$18.10)

• Investment tax credit:

IOU's in all four comparisons - see direct grants because a tax credit to an IOU can usually be used immediately and is therefore equivalent to a grant of equal amount.

*Investor owned utility

In the condensation of the above results from the subsidy analysis, it is clear that the developers with the best financing and tax situation will develop the greatest total amount of SSH capacity and the largest absolute increment in response to almost any subsidy available to both public and private sectors. The largest relative increase in supply in response to a subsidy comes from the developer who, in the base case, would supply the least amount of energy (investor-owned utilities). A subsidy to investor-owned utilities would also cost the least per incremental kilowatt-hour or per barrel of oil saved. In other words, the greatest fuel savings per subsidy dollar is achieved by subsidizing the developer who would otherwise supply the least amount of energy. Conversely, subsidies to municipalities and cooperatives (that supply the most energy in the base case and respond the least in relative terms) will cost the most per incremental kilowatt-hour.

Finally, subsidies to similar potential SSH sites in the mid-Atlantic region or New England might still be cost effective, but less so than in the South Atlantic area. Higher energy costs in these areas are inducing more SSH development than is currently possible in the South Atlantic area. With more of the resource base already developed or developable, the average cost of subsidies per incremental kilowatt-hour in these higher-energy-cost areas would be

higher. Since the cost effectiveness of federal subsidies available to the entire country would vary from region to region, statewide or regional subsidy programs might then be most efficient.

FUTURE PLANS

Future work on this project is limited to the publication of the detailed method and the results of estimating future development at the 22 sample sites by the above classes of developers (Ref. 4).

REFERENCES

1. Small Hydro Bulletin, Vol. 2, No. 3, Aug 1980, pp. 5-10 (prepared for DOE, Division of Hydroelectric Resources Development) by Idaho National Eng. Lab.
2. W. Barron, "A Review of Recent Energy Price Projections for Traditional Space and Process Heating Fuels in the Post-1985 Period," JHU/APL GEMS-007, Apr 1980, p. 22.
3. "Monthly Energy Review," U.S. Department of Energy, DOE/EIA-0035/80(07), Jul 1980, p. 72.
4. F. Bennett, S. Briscoe, and H. Henderson, "Problems of Hydroelectric Development at Existing Dams, An Analysis of Institutional, Economic, and Environmental Restraints in North Carolina, South Carolina, and Georgia," JHU/APL HE-005 (to be published).

NEOTECTONIC INVESTIGATIONS OF THE MANHATTAN PRONG

APL has been engaged in a field investigation of the causes of seismicity in southeastern New York and western Connecticut since mid-1979. Mapping of fault zones and stratigraphic relationships has been conducted from Southbury, CT to Mt. Kisco, NY.

Although no field work was done during this quarter, a synthesis of published regional

data and the results of the author's work over the past five years were written and submitted to the Nuclear Regulatory Commission (NRC) for distribution as an NUREG report. Copies will be available upon request (Ref. 1).

Major findings include the delineation of several newly identified large fault zones, definition of the sequence and style of brittle

Fig. 1 Geologic setting and major faults of the northern Manhattan Prong. (80-3/77)

Fig. 2 General location of Manhattan Prong area. (80-3/78)

deformation across the Manhattan Prong, and identification of methods for establishing detailed Cenozoic faulting histories. The fault zones that were identified are: the Croton Fault, the Saw Mill River Fault, the Ridgefield Fault, and the Georgetown Fault (Fig. 1). Figure 2 shows the general locale of Fig. 1. The zones strike northeast and have experienced multiple episodes and senses of displacement. Several of them are known to have been active in the Mesozoic. A comparison of epicenter distributions with the new fault map of the Manhattan Prong reveals that seismic events occur in the vicinity of these newly identified faults; one strong alignment of epicenters lies parallel with and just southeast of the surface trace of the Saw Mill River Fault (Fig. 3). The Cenozoic tectonic histories of these faults need to be established.

Fig. 3 Seismicity of the Manhattan Prong vicinity. (80-3/79)

FUTURE PLANS

In order to determine the magnitude of slip (offset) along these fault zones, detailed stratigraphic analysis will be performed in the Danbury Quadrangle during the coming year. Brittle fracture analyses are also planned for the younger rock types in this region in order to separate and date the various periods of deformation.

REFERENCE

1. J. E. Tillman, "Brittle Deformation of the Manhattan Prong," JHU/APL QM-80-104, Aug 1980.

ENERGY CONVERSION AND STORAGE TECHNIQUES

Cooling with Modest Geothermal or Solar

§ 23

Temperatures X8D2CQO

Support: IR&D

J. W. Follin, Jr., and K. Yu

July-September 1980

EVALUATING THE EINSTEIN REFRIGERATOR

In a recent commentary (Ref. 1), Alefeld briefly reviewed the Einstein-Szilard absorption refrigerator (Ref. 2) with three working fluids, $\text{NH}_3/\text{H}_2\text{O}$ /butane (Fig. 1).

As the discussion below shows, it appears that the Einstein-Szilard refrigerator can be operated with the modest source temperatures (say, 150°F or below), that are readily available from eastern geothermal resources, solar, or co-generation systems. Unlike the better

known Electrolux Servel system (based on the von Platen and Munters patent), which uses hydrogen as an inert gas to equalize the internal pressure and $\text{NH}_3/\text{H}_2\text{O}$ as the working and absorbing fluid, the Einstein-Szilard absorption refrigerator (ESAR) uses a condensable gas (butane) to equalize the pressure. This liquid (butane) was chosen because in the liquid state it does not mix with the $\text{NH}_3/\text{H}_2\text{O}$ solution. Further, in the ESAR, the NH_3 vapor is used mainly as the "pump" for the butane vapor from the evaporator (1 on Fig. 1) to the absorber (6). Thus, the cooling in the evaporator comes mainly from the latent heat of butane. A feature common to the ESAR and the Servel system is that there is no mechanical, moving component such as mechanical pumps or valves. In the ESAR, the fluid is circulated through the bubble pump (36); in the Servel system the circulation is accomplished by boiling off the $\text{NH}_3/\text{H}_2\text{O}$. As the heat is put into the solution in the generator tank (29), the NH_3 vapor (nearly dry saturated vapor) is evolved with water that remains mostly in liquid state. This avoids wasting the large latent heat of water. More important, the use of sat-

Fig. 1 Einstein-Szilard absorption refrigerator. (80-3/80)

Fig. 2 Theoretical cooling capability of Einstein refrigerator per pound of NH_3 gas. (80-3/81)

urated "equilibrium" vapor allows the system to be driven at a source temperature much lower than is possible with any other known refrigeration system.

DISCUSSION

During this quarter, the performance of the Einstein-Szilard refrigerator was estimated through a simplified analysis (Ref. 3) in order to assess the possible application to the low-temperature (i.e., lower than 160°F) geothermal resources of the eastern United States. For simplicity, it was assumed that the two internal heat exchangers are perfect and that the gases are ideal. For this analysis the effects of the

continuous temperature distributions in the generator, absorber, and evaporator, as well as the effect of the presence of water vapor, were ignored.

Figure 2 is a plot of cooling temperature versus heat load for four operating conditions for a fixed flux of gaseous NH_3 . The exponential shape of the curves is controlled by the vapor pressure curve of butane. The change in the butane to the NH_3 flux ratio and the butane enthalpy changes are reflected in these curves.

The theoretical performance estimate is quite encouraging. Taking the temperatures as 80°F (condensor), 140°F (generator), and 50°F (evaporator) for the NH_3 weight fraction of 0.52 in the strong solution (in the condensor) and an NH_3 vapor flux of 1 lb/min, the heat fluxes are 588 Btu/min for the geothermal source and 148 Btu/min for the evaporator load. An estimated efficiency is obtained of 0.252, where the additional contribution arising from the isobaric expansion of NH_3 vapor in the evaporator has been ignored. It is expected to contribute about a 10% increase in the cooling Btu. This performance is extremely interesting, particularly because no other refrigeration system can provide a comparable capability with a source temperature of, say, 145°F without requiring a significant amount of high grade (electrical) energy.

FUTURE PLANS

More extensive calculations are planned for the future to map the performance of the Einstein-Szilard refrigerator. Other refrigerant combinations will also be investigated in an effort to find a set more appropriate for geothermal application.

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OTEC PILOT PLANT PERFORMANCE CALCULATIONS

A potentially cost-effective option for OTEC heat exchangers using shell-less, folded 3-in. OD aluminum tubes is being studied at APL. Vertical planes of these tubes (seven nested tubes per plane), connected in parallel, form a heat exchanger module, illustrated as a condenser in Fig. 1. The same tube arrangement applies as an evaporator. Seawater is pumped to a head pond above the module and flows downward by gravity to either evaporate or condense ammonia, the working fluid inside the tubes.

A full-scale core unit of this heat exchanger concept was tested as an evaporator and as a condenser to establish a performance data base from which the heat exchanger of an OTEC pilot plant could be designed. The results of those tests and their incorporation into APL's performance simulation were previously reported (Refs. 1 through 4). Using this updated analytical simulation, heat exchangers for a 40-MWe(net) power system were outlined, and the performance at off-design ocean temperatures were calculated as presented below.

Fig. 1 5.0 MWe (net) condenser module having 2.65×10^5 ft² (2.3×10^4 m²) (nominal) surface area. (80-3/82)

DISCUSSION

An updated analytical description of a 40-MWe(net) power system using eight 5-MWe(net) modules (comprising one evaporator and one condenser per module) was developed. The baseline ocean water temperature difference (ΔT_o) was taken as 42°F; the water velocity through the minimum gap in each heat exchanger was set at 2.5 ft/s. Efficiency and loss factors were revised so that the values used in this analysis are comparable to those used to evaluate other OTEC systems (Ref. 5). The resulting predicted performance of a module configuration, as outlined in Table 1, with 69 rows of 7 nested-tubes per row, was 41.1 MWe(net) with an ammonia flow of 1.5 lbm/s/tube through the evaporator and an evaporator exit quality of 45.2%. A shipboard hotel load of 400 kW was not explicitly taken into account in these calculations; therefore, this baseline design yields $(41.1 - 0.4) = 40.7$ MWe(net) power. An odd number of nested-rows per module is desirable because of cleaning considerations (Ref. 6). For a 67 row baseline case, the net power produced (39.6 MWe) fell below the requirements so the next greater odd number was chosen.

Table 1

Baseline design characteristics for 40-MWe (net) pilot plant.

Geometry	
No. of heat exchanger modules	8
No. of tube rows per heat exchanger	69
No. of tubes nested per row	7
No. of horizontal passes per tube	25
Height of module	64.0 ft (19.5 m)
Width of module	27.5 ft (8.38 m)
Length of module	24.8 ft (7.56 m)
Horizontal pass length	23.3 ft (7.10 m)
Height of head ponds	6.88 ft (2.10 m)
Module area for hot water flow	241.5 ft ² (22.4 m ²)
Module area for cold water flow	249.4 ft ² (23.2 m ²)
Cold water pipe inside diameter	30.0 ft (9.14 m)
Cold water pipe length	3000 ft (914 m)
Hot water inlet diameter	16.97 ft (5.17 m)
Efficiency and Loss Factors	
Turbine efficiency	88%
Turbine generator	97.5%
Ammonia pump and motor	72%
Hot or cold water pump	86%
Hot or cold water pump motor	94%
Head loss coefficient for water pipes	0.20
Pressure drop across separator	0.30 psi (2.1 kPa)
Euler number for water flows	0.10
Evaporator two-phase friction constant	7.0
Evaporator bend loss coefficient	2.0
Condenser two-phase friction constant	10.0
Condenser bend loss coefficient	1.5

Table 2

Operating characteristics for 40-MWe (net) plant at on- and off-design conditions.

Water velocity in minimum gap (Vw)	2.5 ft/s (0.76 m/s)
Hot water flow through module	38,700 lbm/s (17,600 kg/s)
Cold water flow through module	40,000 lbm/s (18,200 kg/s)
Cold water temperature (TCW)	40.2°F (4.56°C)
Fouling factor (evaporator and condenser)	0.0002 Btu/h-ft ² -°F (0.000035 W ⁻¹ -m ² -K)

Ocean temperature diffuser °F (°C)	Hot water temperature °F (°C)	Gross turbine power (MWe)	Evaporator ammonia flow*	Evaporator exit quality (%)	Evaporator overall U**	Condenser overall U**	Net power (MWe)
44 (24.4)	84.2 (29.0)	55.7	1.51 (0.69)	45.0	466 (2640)	441 (2500)	45.8
42 (23.3)	82.2 (27.9)	50.9	1.51 (0.69)	45.2	464 (2630)	441 (2500)	41.1
40 (22.2)	80.2 (26.8)	46.1	1.51 (0.69)	45.1	462 (2620)	441 (2500)	36.4
38 (21.1)	78.2 (25.7)	41.1	1.51 (0.69)	45.0	459 (2600)	441 (2500)	31.5
36 (20.0)	76.2 (24.4)	36.2	1.50 (0.68)	45.0	456 (2590)	441 (2500)	26.7
34 (18.9)	74.2 (23.4)	31.2	1.50 (0.68)	44.9	453 (2570)	441 (2500)	21.8

*lbm/s (kg/s) per tube

**Btu/h-ft²-°F (W⁻¹/m²-K)

U = Overall heat transfer coefficient

Fig. 2 OTEC 40 MWe (net) pilot plant-estimated power versus ΔT_0 . (80-3/83)

Off-design performance predictions were made for this baseline design for varying ΔT_0 by changing the surface ocean water temperature. The results of this study are presented in Table 2. The gross and net power performance (without hotel load) over these conditions is illustrated by Fig. 2.

FUTURE PLANS

The work on establishing a design data base for APL's fold-tube exchanger concept is complete with respect to the clean (i.e., nonfouled) performance. The modified simulation is available for use in future development of these heat exchangers pending sponsor support.

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STUDY OF LANDFILL METHANE RECOVERY

Methane, the major constituent of natural gas is formed along with carbon dioxide in sanitary landfills as the organic matter deposited there decomposes. This landfill gas, typically 60% methane and 40% carbon dioxide, can be recovered and, with relatively little treatment, used as an energy source.

APL has recently completed field tests for a feasibility study to provide preliminary estimates of the quantity and quality of the gas present for possible recovery at two landfills. The study was made for the National Capital Region of the National Park Service (NPS) at the Kenilworth and Oxon Cove landfills in the Washington, D.C., area.

DISCUSSION

Probe and Well Installation. The first phase of the testing program involved installing 15 test probes at Kenilworth and 8 at Oxon Cove. The test probes consist of 1/4-in.-diameter polyflow polyethylene tubing incased in 1-in.-diameter polyvinyl chloride (PVC) pipe, ranging from 6 to 22 ft in length (see Fig. 1). Bore holes for the probes were drilled with a 4-in.-diameter auger. After the probes were in place, the bore holes were backfilled with gravel and sealed with a few feet of compacted cover material.

The probes were used initially to obtain estimates of the quality of landfill gas present at various locations. Static landfill gas samples were collected at the probes and analyzed by gas chromatography. The concentration of methane in the landfill gas was used to determine the location of the larger test wells described below.

Nine test wells were installed at Kenilworth and seven at Oxon Cove. The test wells were constructed with 3-in.-diameter PVC pipe, as shown in Fig. 2. The pipe ranged in length from 8 to 20 ft and the lower 5 ft were slotted. The wells were placed in 10-in.-diameter bore holes. The bore holes were backfilled with gravel and sealed with compacted cover material. Methane concentrations in the landfill gas samples collected from the test wells determined which wells would be selected for later pumping tests. Those wells were given an additional seal of approximately 1 ft of concrete.

Static Test Results. At the Kenilworth landfill, a wide range of methane concentrations was found, from 0 to 98% by volume. (It should be noted that the 0% concentration was obtained from a test probe intentionally located outside the landfill area.) Two regions of the landfill with high methane concentrations were identified. In addition to the methane, the landfill gas typically contained nitrogen and carbon dioxide.

At Oxon Cove, the methane concentration was fairly constant in gas samples taken throughout the landfill area. It ranged from 51 to 80% by volume. The landfill gas typically was comprised of almost entirely methane and carbon dioxide. Usually small amounts of hydrogen were present.

Pumping Tests at Kenilworth. Pumping tests were conducted on a continuous 24-hour basis for a period of two weeks at two test wells (wells

Fig. 1 Probe design. (80-3/84)

Fig. 2 Test well design. (80-3/85)

1 and 8) at Kenilworth. Landfill gas was withdrawn from the landfill with a blower driven by a 5 hp electric motor. A moisture knock-out box was installed between the well and the blower intake. The well head was connected to the knock-out box by flexible PVC duct; flow was controlled by a manual valve located at the blower. The flow rate of the landfill gas, the internal pressure of the landfill at nearby probes/wells, and the composition of the landfill gas were monitored during the pumping periods.

During the pumping test at well 1 at Kenilworth, gas analyses revealed a range of heating values from 684 to 777 Btu/cf of gas, with an average value of 750 Btu/cf. (The heating value is based on pure methane having a net heating value of 913 Btu/cf.) The gas quality remained fairly consistent throughout the two week period, as may be seen in Fig. 3. The average gas composition was 82% methane, 13% nitrogen, and 5% carbon dioxide. The flow readings ranged from 36 to 54 cfm and averaged 44 cfm. Over the course of the pumping period, an estimated $0.9 \times 10^6 \text{ ft}^3$ of landfill gas were withdrawn. While pumping at well 1, well 2 and probe 14 were tested for gas composition and pressure. There was no apparent effect on the gas composition as a result of the pumping.

During pumping at well 8 at Kenilworth, analysis indicated a range of 726 to 864 Btu/cf gas, with an average of 796 Btu/cf. Figure 4 shows the measured gas concentration over the two week pumping period. The gas had an average composition of 92% methane, 4% carbon dioxide, and 4% nitrogen. Flow readings varied from 53 to 82 cfm and averaged 62 cfm. An estimated $1.3 \times 10^6 \text{ ft}^3$ of landfill gas were withdrawn at well 8. Gas composition and pressure at probe 14 (90 ft away) were monitored while pumping at well 8. The gas composition was not affected at the probe.

Venting Tests at Oxon Cove. Since the internal pressure of the Oxon Cove landfill ranged from 7 to 20 in. of water higher than the barometric pressure (probably caused by the thick layer of cover material), two wells (4 and 5) were allowed to vent naturally. For almost four weeks, flow rates, landfill gas composition, and internal landfill pressures were monitored at Oxon Cove. During this venting period, the sampled landfill gas contained approximately 60 to 64% methane, 36 to 40% carbon dioxide, and 0 to 0.1% hydrogen.

Figure 5 shows the relatively constant gas concentrations while venting at well 4. The average composition was 62% methane and 38% carbon dioxide, and the heating value of the gas ranged from 550 to 579 Btu/cf and averaged 562 Btu/cf. Gas was venting at an average flow rate of 51 cfm. During the venting period, an estimated $1.8 \times 10^6 \text{ ft}^3$ of landfill gas escaped.

Gas analysis results at well 5 during the period of venting are shown in Fig. 6. As was found at well 4, the average gas composition was 62% methane and 38% carbon dioxide. The heating value of the gas ranged from 549 to 579 Btu/cf and averaged 562 Btu/cf. The average flow rate of the gas was 57 cfm. An estimated $2 \times 10^6 \text{ ft}^3$ were vented during the testing period.

While venting at wells 4 and 5, gas compositions and pressures were monitored at nearby locations. Venting did not appear to effect the gas composition at any of the locations.

Utilization of the Landfill Gas. The results at both Kenilworth and Oxon Cove indicate favorable conditions for the recovery and use of the landfill gas.

Fig. 3 Gas concentration while pumping at Kenilworth well 1. (80-3/86)

Fig. 4 Gas concentration while pumping at Kenilworth well 8. (80-3/87)

The planned end uses of the landfill gas at Kenilworth include providing the space heating and electricity requirements at the Kenilworth greenhouses, which are located nearby. In addition, the Aquatic Garden greenhouses located between the landfill and the Kenilworth greenhouses may also be supplied with the landfill gas.

The fairly stable level of methane concentrations (75 to 85%) at Kenilworth well 1 at flow rates ranging from 36 to 65 cfm indicates that the capacity of the well was not overloaded during the two weeks of pumping. Three such wells, with an average withdrawal rate of about 25 cfm at each, could provide the estimated max-

Fig. 5 Gas concentration while venting at Oxon Cove well 4. (80-3/88)

Fig. 6 Gas concentration while venting at Oxon Cove well 5. (80-3/89)

imum monthly rate of 75 cfm of medium Btu (500 Btu) landfill gas needed by the Kenilworth and Aquatic Garden greenhouses. This takes into account that the heating value of the landfill gas might drop from the average 750 Btu/cf seen during the pumping period to 500 Btu/cf once pumping has been continued for some length of time. A collection system consisting of five or six wells would not only yield enough landfill gas for the greenhouses but would also provide flexibility so that, if problems were encountered with a well, the well could be removed from the system without shutting the system down.

The recovery system could be designed to use the gas generated in the northern portion of the landfill. The recovery wells should be spaced at approximately one per acre. The recovery well design may be similar to the test well design, and at least one of the test wells could be used as a recovery well. The recovery wells should be equipped with a valve at each well head so that the flow from each well can be controlled. The design should provide for access to each well head to allow for testing.

It can be expected that the entire northern section of the landfill would be reserved for use by the greenhouses. Because of the unusual nature of the gas composition (unusual because of the high methane content, possibly a result of slow methane production and/or high ash content of the landfill) and the uncertainties involved in the prediction of the life of the landfill gas generation, it is advisable to develop this one area and to continue testing. It may become necessary to use portions of the southern part of the landfill for the greenhouse application. However, if the landfill continues to generate gas at an acceptable rate with a reasonable methane concentration, alternative uses can be investigated for the gas in the southern area of the landfill.

At Oxon Cove, static and venting tests indicate that there is a significant quantity of medium Btu (500 Btu) landfill gas available at a relatively high pressure. (The cause of the pressure is not fully understood, but could result from various factors, including a high percentage of moisture in the landfill.) Since the end use for the landfill gas at Oxon Cove has not yet been fully determined, it is recommended that an end-use study for the gas be performed, assuming that at least 300 cfm of gas is available. One possible use of the landfill gas is to provide electricity and/or space heating for the buildings of the Oxon Hill Farm. Use of the landfill gas to generate electricity for sale to the local utility should also be explored.

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