TECHNOLOGY CHARACTERIZATIONS

Environmental Information Handbook

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FOREWORD

The business of the public sector is to make governmental policy decisions and to implement those already made. These activities demand considerable amounts of time and resources. Furthermore, they require the gathering and analyses of large amounts of information for successful operation and completion. Policy debates, often conducted in a hurried atmosphere, initiate an immediate requirement for new analytical information for a particular issue under consideration. When a new subject is begun, the previously developed information is set aside to be used later for similar discussions. Then, the users tend to be the same people who were familiar with the prior data base.

Information developed in this manner is generally not available to the open literature. This is true not because of any desire for secrecy, but because it takes time and resources to organize information for purposes other than policy decision inputs. The inclination is usually lacking in the bureaucracy to take the additional time and spend the resources to transform information for other uses or even to initially develop it in a format for additional possible applications. Furthermore, there is often the suspicion that public sector information from a mission agency is not apt to be totally unbiased, and this can result in tacit dismissal.

The Environmental Handbook Series is designed to overcome the deficiency of information utility and transfer. Each of the works in this series will bring together information in an area and format that is useful to both public and private sector needs. It is meant to serve as a basic reference document that will stand for a period of time and help to enrich decisionmaking and research in the interface of energy and the environment.

Further, the production of summary documents, such as in this Handbook, helps to more sharply focus the adversarial nature of policy debates. By making explicit the information base available and by exposing it to peer review prior to input into policy deliberations, an organization insures the credibility of the data, or has a basis for not using it. The policy debate then narrows considerably as the quality of the technical detail is substantiated.

This particular handbook deals with environmental characterization data for the energy technologies and presents the data in a format for use by DOE policy analysts. This treatment includes not only the actual information base, but also a Preface which explains the present concept, the historical growth of the program, and the new direction for improved utility. The information base, itself, is constantly being enhanced and is republished periodically as necessary.

The development and maintenance of the Environmental Characterization Information Base is the responsibility of the Technology Assessments Division. Assistance was provided by The Mitre Corporation in the preparation of the summary information sheets, and by the Aerospace Corporation in the development of the draft Environmental Information Characterization Report (Appendix A). Special acknowledgement goes to Albert E. Fry, consultant, for assistance provided in the preparation of the Preface.

Peter W. House, Director
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PREFACE

Environmental Information Requirements for Energy Technologies

The availability of quality energy-related environmental information for use by the Department of Energy is essential for evaluating alternative energy policies and technology strategies, and for carrying out responsibilities assigned by the Congress. Environmental information is required for two different purposes. First, the Department conducts strategic energy policy and planning analyses which forecast the future levels of U.S. energy consumption and supply as well as the shares to be provided of the various fuels by the competing energy technologies. Second, the Department plays a leading role in the development and advocacy of specific new energy technologies. Simply stated, energy planners are seeking to determine how much energy will be required and produced domestically, and how much of this domestic share will be produced from the various energy sources. Strategic energy planning should include an assessment of the environmental implications of the various energy generating technologies. The relative success or failure of the competing energy technologies depends upon economic, engineering and environmental considerations. These considerations are inseparable since engineering design modifications and the implementation of additional control technologies can reduce pollution residuals at some added cost, efficiency and safety of the energy technologies involved.

The Department also needs environmental information for other program requirements ranging from the preparation of Environmental Impact Statements to working with the Environmental Protection Agency in the development of environmental regulations for emerging energy technologies. Department of Energy environmental information is often used by State and Local planners, by public interest groups, and by the business community in the process of formulating industrial policy. However, the first two purposes identified are representative of the Department of Energy's needs in this area and also provide a focus for identifying certain inherent problems with the information.

To conduct strategic energy policy and planning analyses, national or regional energy models are usually employed. Given existing resource and time limitations, collection of accurate and current information for each individual energy facility is costly. Energy analysts are forced to rely on limited information for existing or hypothetical facilities for estimating the environmental impacts. For example, the analyst may rely on real data from existing plants collected by the Environmental Protection Agency or State environmental control agencies, or, based on existing and proposed environmental regulations, the analyst may develop a representative model of future plants and extrapolate existing data to fit the representative model. No real plant will match this model plant precisely since site specific conditions, coal type, system components, engineering design, environmental control technology and other factors may vary somewhat from the model in reality. Over a reasonable sample size this representative plant works very well. But for a single site specific plant there will be variations from the expected information. The problem of ascribing data to hypothetical facilities is heightened when dealing with new

emerging technologies, which are usually dependent upon a limited number of prototype or demonstration facilities and may not reflect future reality.

The description of most model process systems with the related data can always be improved since more resources enable the analysts to perform a more comprehensive study, and apply more quality control. Data elements in particular, always require continuous validation and updating. A problem facing every information manager is the determination of which information requirements can be satisfied within given budgetary constraints. For analyses required to support the development of emerging new energy technologies, the level of specificity of environmental information desired is very high. The program manager needs assurance that information is generated from an engineering design or operation which most accurately reflects the program manager's current projection of the specific energy technology to be carried through to commercialization. The fewer the number of existing facilities, the more difficult it is to develop a representative model plant. If the analyst attempts to average a wide range of estimates, the decision makers find that the information is no longer useful.

In summary, environmental characterization information needs to meet both the general requirements of the strategic energy policy planner and the more specific requirements of the managers of developing technologies. Additionally, the information should be documented, verifiable, consistent, current and available in a format applicable to the diverse users inside and outside the Department.

Evolution of the Activity

The conception of the Environmental Characterization Information activity began with information requirements for the Strategic Environmental Assessment System (SEAS). SEAS, a mathematical model for assessing environmental impacts on a national scale, was originally developed by the Washington Environmental Research Center of EPA. Subsequently, use of this model was incorporated into the analyses conducted by the Energy Research and Development Administration (ERDA) Assistant Administrator for Environment and Safety. SEAS contains extensive environmental data files which were drawn initially from a wide range of sources such as the EPA National Emissions Data System, the EPA New Source Performance Standards and Effluent Guidelines, Hittman Associates "Environmental Impacts, Efficiency, and Cost of Energy Supply and End Use" (Contract for CEQ), the EPA "Cost of Clean Air" and "Cost of Clean Water," and the EPA "Industry Studies."

Subsequently, additional data from the Bureau of Mines, Federal Power Commission, Federal Energy Administration, Brookhaven National Laboratory and from ERDA's Market Oriented Program Planning Study (MOPPS) were added to the SEAS data bases. The data developed were normalized to 10¹² Btu of energy output for use by the model. These extensive environmental data bases, despite existing inadequacies, comprised the most complete data set of environmental characterization information available to ERDA and subsequently to the Department of Energy.

In 1977, with contractual assistance from the MITRE Corporation, Consad, Inc., Control Data Corporation, and International Research and Technology, Inc., SEAS was used by ERDA to produce the information for the first Annual Environmental Analysis Report which provided a national and regional analysis of President Carter's first National Energy Plan. Distributed widely, the report became an important element in the energy policy debate which followed. In 1978, the Office of Technology Impacts, under the DOE Assistant Secretary for Environment, accelerated the validation and updating of the data in SEAS. As an integral part of this activity, a series of documents gradually evolved which presented comprehensive environmental data on the environmental pollution potential of the various energy technologies.

The first step was the production of summary data sheets for a set of energy technologies. These summary sheets were generated in a format which reflected SEAS requirements. The first volume, "Environmental Data for Energy Technology Policy Analysis," was published in January 1979, with a supplement adding several new technologies appearing in August 1979.

In January 1980, a revision entitled, "Environmental Data/Energy Technology Characterizations" was issued. Approximately one-half of the data summary sheets had undergone considerable revision with improved quality control and data source documentation. In addition, supplemental publications for each major energy fuel source (coal, nuclear, petroleum, solar, etc.) have since been prepared to explain the methods used to develop the summary volume. The chapters in each supplementary volume, relating specifically to the organization of the summary, begin with a brief description of standard characteristics, size, availability, mode of operation, and place in the fuel cycle. Next, major legislative and/or technological factors influencing the commercial operation of the activity are identified as well as coefficients for resources consumed, residuals produced, and economic information. The data summary sheets presented in subsequent pages of this publication complete the major revision begun in January.

Present Limitations

The purpose of the present activity is to present environmental characterization information in a useful format for environmental policy and planning analyses relating to energy technology development and deployment. The information should represent the best available data on resource requirements and environmental effects for each principal energy technology considered.

Evaluation of the present information base has revealed inherent weaknesses. Some data are inconsistent with the base model description, some are based on faulty assumptions or outdated engineering designs, some data have been entered incorrectly into the system, and some elements have been derived from studies of questionable validity. As a result, approximations have been made by analysts. Also, missing data are prevalent, particularly for coal conversion and other new technologies. While approximations assuming reasonably valid and consistent information are ordinarily adequate for general environmental policy and

planning activities, this approach is not adequate for site specific analyses. If one is concerned with the distribution of plants across the country, then the information can be used to develop estimates of the total loadings in a particular geographic region, representing the total environmental impact for that region.

Although aggregations of the residuals can be computed in this way resulting in an understanding of the changes or rates of changes of total pollutants in the environment, problems remain. The information in "Environmental/Energy Data Characterizations" is not realistically representative of specific operations nor realistic in terms of being able to identify the need for particular control equipment that might have modified these systems. In many cases, the hypothetical plant on which the characterization is based is an average of several installations which may have used different technological bases. The energy systems used to develop the model plant vary in character and raw material input requirements. The hypothetical basis is ineffective for real world analyses.

While the net result of the present effort has significantly improved information, certain deficiencies in consistency and reliability remain. Because the data have been derived from multiple sources, the numbers represent outcomes of engineering analyses which have been developed using different criteria. The residuals computed for a particular type of technology are sometimes derived from the analyses of two or more specific engineering systems, each behaving differently and discharging different levels of residuals. Moreover, in addition to not using standard criteria for base system selection, certain parameters have been derived by calculations which do not have a clear relationship to a specific engineering system. Consequently, the environmental residual coefficients combined in the summary volume as a single value are not always consistent in representing actual residuals output. Failure to apply standard criteria from component to component within the process results in certain of the environmental residual coefficients being noncomparable to other coefficients within the same technology or the other technologies.

Because work has continued on the development of engineering systems, specific information has become available over time on new energy technologies. In particular, operating data from pilot operations and more detailed designs have become available. This presents a unique opportunity to take the next logical step to improve the information base by substituting this new engineering specific environmental data. In cases where actual data based on engineering operations is not yet available, computations and energy balances can be made to provide information about the unit operation and steps within the overall process. A more accurate and detailed set of information including operating parameters, resources, and environmental pollutants under specific conditions of energy generation and operation of facilities would result. This would provide the user not only with better information for decision making at the policy level, planning, and identification of environmental control requirements, but also with information which identifies the need for specific environmental R&D and control technology data. It would also provide DOE with

specific environmental information for the analysis of systems being developed at particular sites. The value of this information for environmental impact assessment to satisfy NEPA requirements would be an important example. All these considerations point to the need for a new programmatic approach.

Future Direction

The development of a new approach will significantly alter the present process. Instead of environmental information flowing from the SEAS data base to the information file, the process will be reversed. Environmental characterization information will be derived through a detailed engineering analysis of a specific energy technology process, and developed through an Environmental Characterization Information Report. The process specific data sheets will be pulled together in a summary volume for all technologies. This new information will be available to augment SEAS as appropriate. The next section will outline the proposed changes in the system and describe the Energy Characterization Information Report concept.

If environmental characterization information is to effectively serve planning and analyses by the Department and other users, the information contained in the file must be at a level of quality that will ensure its acceptance and use. As noted above, the Office of Technology Impacts has determined, after objective appraisal, that the quality of information must be improved. The improvements will be directed at enhancing several important quality attributes of the information; its representative character, its inherent consistency and validity, and its currency. Users of the information will be able to track or replicate the data independently. This means that all initial calculations or subsequent revisions will be explicitly documented. Accordingly, the Office of Environment is establishing a revised approach for conducting these related activities, as described in Figure 1.

(Figure 1 is shown on the next page.)

ENVIRONMENTAL CHARACTERIZATION INFORMATION PROGRAM

All information developed through the new approach will be subjected to technical review 1 conducted by the appropriate technology specialist from the Office of Technology Impacts consulting with recognized experts in the related fields. The activity to develop the information and present it for technical is the central element in this new system. The final presentation of the characterization information will be the report 2. Each report will be technology specific. Basic information developed in the report will be used for updating the automated information base 3 and for preparing the summary volume 4 which encompasses all of the energy technologies. The automated information base can be used to transfer the data automatically to other Departmental users 5 as appropriate.

A report will be prepared for each specific energy base system. It will represent one or typical elements of an energy fuel cycle. The basis for the characterization information in the report will be a specified energy technology system typical of systems in current operation or under development for eventual commercialization. Since it is not feasible to produce a characterization for every possible system variant, the selection will insure, as availability permits, that the energy technology system chosen for characterization is representative of actual systems and broadly representative of a segment of the overall energy supply or conservation system. By associating the characterization information with actual systems, the credibility of the information will be enhanced for systems of that type. There are components of an emerging energy technology system which equate to actual functioning systems and for these components the information represented will be accurate and can be used for purposes of predicting how a particular segment of a new system might function in the future. The representation can be regarded as highly reliable because it is closely based upon real or as near to real system data as is obtainable.

In the Environmental Characterization Information Report, the analysis of resource requirements, environmental residual coefficients, and certain impacts will be carried out for each major component and environmental point-of-interest in the system. The system will be graphically portrayed with all environmental points-of-interest identified and related to the narrative discussion in the text.

The assumptions and methods used to derive the information will be clearly shown. Information will be taken either directly from the technical literature (if its validity and usefulness is confirmed by qualified experts) or extrapolated by computation or by suitable estimating technique from such information. In instances where information is not available directly, a valid estimating method may be employed and will be documented. For those components of the process that are not fully developed, the best available experimental information will be used.

The results of this new approach, to managing the selection, review and presentation of the information, should represent a significant step forward in providing useful information for environmental analyses and planning. The fundamental advantages for adopting this approach are several:

- o a baseline will have been established for focusing continuing review, and update of environmental information,
- o the baseline will provide a common reference point for individual users to extrapolate from with respect to their specific situations,
- o the user will have assurance that all information in the file has been subjected to expert review,
- o the user will have an accessible, easy to understand, and well documented presentation showing the derivation of information for each environmental point-of-interest in the system,
- o standard criteria for environmental information development will be used, and,
- o availability and relevancy to other Departmental programs will be enhanced.

To illustrate the new approach, a draft prototype Environmental Characterization Information Report has been developed for a new coal-fired power plant burning typical Eastern United States bituminous coal. The prototype Report is in Appendix A.

In this instance, the best available characterization of both the technology and its associated impacts were developed for each step and module in a specific engineering design. For each component step or module, computations were carried out based upon the best information available in order to specify what the environmental characterization of that particular module would be and to put the results in terms and dimensions convenient to the user. The information is expressed in conventional engineering units, metric units, and in terms compatible with computer modeling requirements. Coefficients are expressed for a variety of parameters of interest:

Resources

Coal Consumption
Water Consumption
Raw Materials
Land

Environmental Residuals

Air Pollutants
Water Contaminants
Trace Metals
Solid Wastes
Heat Losses

Further development of the prototype will include information relevant to capital costs, pollution control costs, manpower requirements, more occupational health and safety factors, and other parameters as needed. The information will be uniformly presented in all Environmental Characterization Information Reports. Priority will be given to emerging technologies which are the primary focus of DOE's energy policy analyses. Ultimately, as resources permit, a complete library of these reports will be developed comprising about 50-60 energy technology systems of interest. Initially, the program will focus on those conventional and emerging energy systems that are critical to National energy policy in the near and intermediate term. Subsequently, second and third generation technologies for use in the 1990 era will also be addressed. These will be evolving documents and will be revised as appropriate.

Summary

In conclusion, this revised activity is designed to overcome discrete deficiencies in the present system. The new approach emphasizes realistic representation and expert verification. Information sources, calculations, or data manipulations will be documented. Users of the information will be able to trace the source of the data and have confidence in its credibility.

Environmental Characterization Information Reports will represent a significant advance in specificity, reliability and comprehensive utility over earlier presentations of environmental/energy technology data.

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APPENDIX A	A-1
Environmental Characterization Information Report: Coal Fired Power Plant (Eastern Coal)	

INTRODUCTION

Revised sections of this publication also include new summary sheets for the solar, oil, and gas technologies. Assumptions and methods used to derive the total of summarized information are available as additional volumes. The total library of documentation includes the following:

- Summary (Handbook)
- Nuclear
- Coal
- Petroleum
- Natural Gas
- Synthetic Fuels
- Hydroelectricity

Backup documentation for the solar technologies is available through a variety of reports published under the Technology Assessment of Solar Energy Project. The reports are referenced in this volume on the applicable pages.

The information summarized in this Handbook represents the current status of data development and verification performed by technology specialists in the Technology Assessments Division, Office of Environment. If there are any questions regarding the information presented herein, please contact the technology specialists listed below for further discussions.

Nuclear Energy:	W. Neill Thomasson	353-4327
Coal:	William G. Wilson	353-4414
Synthetic Fuels from Coal:	Bipin C. Almaula	353-4401
Petroleum and Natural Gas:	George J. Rotariu	353-5865
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Geothermal:	Robert P. Blaunstein	353-5849
Hydroelectricity:	Robert P. Blaunstein	353-5849
Conservation:	David O. Moses	353-4665

Comments or questions dealing with the scope or objectives of this program should be addressed to the EV Program Manager, Nevaire M. Serrajian, Mail Station E-201, Germantown (telephone 353-4658).

Notes on the Format

The specific energy systems for which environmental/technology characterization information is provided are grouped as follows:

- o Nuclear Energy
- o Coal
- o Petroleum
- o Gas
- o Synthetic Fuels
- o Solar Energy
- o Geothermal Energy
- o Hydroelectricity

Information for each energy system is presented in a uniform three-column format with one system per page. Because of extensive information on some systems, continuation pages have been included.

The first column "Energy System" provides the basic technical information for the system or process. Included are the following:

- o Size of a typical plant or operating system, which includes typical operating capacities, yields, efficiencies and annual production capacities.
- o Description of the process and its mode of operation.
- o Principal components of the system.
- o Major environmental concerns.

The second column presents information for the resources expended in the operation of the energy system. Included are raw materials or feedstock (the "fuel") needed, land, water, other materials, costs and personnel needs. Because the different energy systems vary widely in size, all resources information is given for a hypothetical energy system or plant of one trillion (10¹²) Btu production capacity.

The third column presents information on environmental residuals and energy products. The residuals listed include air pollutants, water pollutants, radiation, and solid wastes. In cases where the technology is not sufficiently advanced to provide quantitative information, the anticipated pollutants are listed to indicate their existence. Again, because the different energy systems vary widely in size, all residuals and products information is given for a hypothetical energy system or plant of one trillion (10¹²) Btu production capacity.

Nuclear Energy

Open Pit Uranium Mining

MINING SYSTEM:

- SIZE** typical mine size of 5.28×10^5 tons/year
 supports 4.8 model UG
 • 4,600 tons produce 10^{12} Btu/year
 • 0.8 capacity factor
 • recovery efficiency 80%
 • 20 year lifetime

DESCRIPTION

- Open pit mining accounted for about 48% of ore production during 1978. It is done when the ore body lies under relatively friable material at depths up to several hundred feet.

COMPONENTS

- large open excavation
- large pile of earth and rock overburden
- network of operating roads and yards
- flow of mine water pumped into local surface drainage or holding ponds
- shops
- warehouses
- office and changehouse structures
- assortment of heavy earth moving equipment
- blasting
- drill rigs 3 years lifetime

ENVIRONMENTAL CONCERNS

- air emissions from heavy earth moving equipment and blasting
- disposal of mine drainage water
- barren rock and earth overburden containing uranium and its daughter products
- uranium bearing dusts and radon and its daughter emissions from mining operations
- dissolved and suspended uranium and its daughter products in mine drainage water
- reclamation of land
- aesthetic considerations
- trace metal contaminants
- mine tailings disposition
- accident risks - flooding, fire and washout, blasting, heavy equipment accidents and pit wall failure

RESOURCES USED:

(Per 10^{12} Btu Produced)

ENERGY

electricity 11.3 MWh(a)
 diesel fuel, oil, and grease 12,700 gallons(a)

LAND

temporarily committed Acres(a) 2.5
 undisturbed area 1.8
 disturbed area 0.7
 permanently committed 0.1
 total 2.4

WATER

discharged to ground Acres-ft. (a) 11.1

MATERIALS

concrete Tons(1)(d) 17.1
 total steel & castings 0.14
 copper, brass & bronze 32.40
 aluminum & castings 0.40
 manganese 0.19
 chromium 0.15
 nickel 0.07
 cast iron 1.35

COSTS

construction Dollars (1978) (4)(d)
 manpower 110,000
 materials 22,000
 equipment 64,000
 other construction 64,000
 (land rights) (64,000)
 (reclamation during construction) (53,000)
 (interest during construction) (99,000)
 (working capital) (55,000)
 total 264,000
 operation & maintenance 198,000

PERSONNEL

construction (4 years) Man-hours (d) 3.0
 operation 3.5

RESIDUALS AND PRODUCTS:

(Per 10^{12} Btu Produced)

AIR POLLUTANTS

particulates Tons 0.27(a)
 SO₂ 0.43(a)
 NO_x 0.25(a)
 hydrocarbons 0.02(a)
 CO 0.001(a)

WATER POLLUTANTS

suspended solids Tons NA
 dissolved solids NA
 trace elements NA

SOLID WASTE

overburden moved Tons 1.4×10^5 (a)

RADIATION

air Curies negligible(2) (NRC presently recommending emission rate)
 radon and radon daughters

MINING PRODUCTS

uranium ore Tons (3) 4,600 (a)

(1) Selected materials and equipment items.

(2) Negligible because it is rapidly diluted in the atmosphere and has a very short half-life, but some of the daughter elements are long-lived.

(3) The amount of ore mined is adjusted to account for a 9% loss of material in the milling stage because the mill requires a total throughput of 4,200 tons of ore at 0.15 U₃O₈ per 10^{12} Btu output.

(4) Items in parentheses are not included in total.

SOURCE: (a) U.S. Atomic Energy Commission, Environmental Survey of the Uranium Fuel Cycle (Wash. 3249), 1974.

(b) University of Oklahoma, Energy Alternatives: A Comparative Analysis, 1975.

(c) U.S. Department of Energy, Environmental Development Plan - Uranium Mining, Milling, and Conversion, DOE/EU-0038, 1979.

(d) Societal Corporation, Energy Supply Planning Model, 1978.

(e) U.S. Environmental Protection Agency, Energy from the West - Energy Resource Development Program Report, Volume IV, Uranium, EPA-600/7-79-0606, 1979.

Underground Uranium Mining

ENERGY SYSTEM:

- SIZE**
- typical mine size of 1.5×10^5 tons/year supports 1.4 model 180s
 - 4,400 tons produce 10^{17} Btu output
 - 0.8 capacity factor
 - recovery efficiency 80%
 - 20 year lifetime

DESCRIPTION

- Operations are essentially for deep deposits at depths greater than 400 feet or when the ore lies under rock strata requiring a great deal of blasting.

COMPONENTS

- service buildings
- haul frame with a truck loading facility
- mine waste pile
- flow of water pumped to surface storage or drainage from underground sump
- shops
- warehouses
- changehouse
- office
- underground tunnels ranging up to a mile or more
- mine shaft vents

ENVIRONMENTAL CONCERNS

- contaminated mine drainage water from underground workings containing dissolved and suspended constituents including particulates, radium, radon, uranium and its daughter products, as well as toxic metals
- releases of radon and radon daughters, rock dust, and radioactive gases into mine air and from mine vents
- accident risks - power failure of ventilation system causing buildup of radon gases, flooding, electrocution, fire, accidents with heavy machinery used for excavating and transporting rock, blasting, and failure of mine roofs and walls

RESOURCES USED: (Per 10^{17} Btu Produced)

ENERGY

electricity
natural gas
diesel fuel

291 MBtu (a)
 1.1×10^6 scf (c)
 1.8×10^5 gallons (a)

LAND

permanently committed

Acres (a)

0.12

WATER

domestic use

Acres-ft (a)

0.2

MATERIALS

concrete
total steel & castings
copper, brass & bronze
aluminum & castings
manganese
chromium
nickel
cast iron

Tons (1)(4)

147.0

94.05

0.55

0.37

0.66

0.07

0.003

1.50

COSTS

construction
manpower
materials
equipment
other construction
(land rights)
(securities during construction)
(interest during construction)
(working capital)
total
operation & maintenance

Dollars (1978) (4)

99,000

55,000

110,000

66,000

(66,000)

(44,000)

(35,000)

(350,000)

330,000

429,000

PERSONNEL

construction (3 years)
operation

Months (4)

1.1

12.3

RESIDUALS AND PRODUCTS: (Per 10^{17} Btu Produced)

AIR POLLUTANTS

particulates
SO₂
NO_x
HC
CO
aldehydes
organic acids

(a)

Tons

0.01

0.02

0.32

0.03

0.19

19.0

0.003

0.003

WATER POLLUTANTS

suspended solids
dissolved solids
radon gas
polonium
lead
blanchet
trace elements

Tons (a)

NA

NA

NA

NA

NA

NA

NA

SOLID WASTE

waste rock

Cubic Feet (a)

1.2×10^5

RADIATION

air
radon and radon daughters

Curies (MRC presently recommending mission rate)

ENERGY PRODUCTS

mined uranium ore

Tons (2)

4,400 (a)

(1) Selected materials and equipment items.

(2) The amount of ore mined is adjusted to account for a 9% loss of material in the milling stage because the mill requires a total throughput of 4,200 tons of ore at $0.22 \text{ U}_3\text{O}_8$ per 10^{17} Btu output.

SOURCES: (a) U.S. Atomic Energy Commission, Environmental Survey of the Uranium Fuel Cycle (Wash. 1248), 1974.

(b) University of Oklahoma, Energy Alternatives: A Comparative Analysis, 1975.

(c) U.S. Department of Energy, Environmental Development Plan - Uranium Mining, Milling, and Conversion, DOE/EDF-0058, 1979.

(d) Rachel Corporation, Energy Supply Planning Model, 1978.

(e) U.S. Environmental Protection Agency, Energy from the West - Energy Resource Development Systems Report, Volume IV, Uranium, EPA-600/7-79-066b, 1979.

Uranium Milling

ENERGY SYSTEM:

- SIZE**
- typical mill size of 1,000 tons/year of Uranium concentrate (U₃O₈) support 3.3 model Light Water Reactors (LWRs)
 - 12.31 tpye yellowcake (75% U₃O₈) produce 10¹⁴ Btu output
 - 0.8 capacity factor
 - recovery efficiency 91%
 - 20 year lifetime

DESCRIPTION

- Milling operations extract uranium from the ore and concentrate it into a semi-refined product called "yellowcake", using both mechanical and chemical processes.

COMPONENTS

- ore storage and blending area
- crushing and sampling building
- mill building containing grinding equipment
- acid or alkaline leach tanks (sulfuric acid or sodium carbonate or bicarbonate are typical)
- solvent extraction building
- thickener
- tailings retention system of about 250 acres
- waste treatment system
- several auxiliary buildings for office and maintenance purposes

ENVIRONMENTAL CONCERNS

- emissions of sulfuric acid fumes, hexose vapors, and dusts from uranium mill processes
- low level radiological pollutant releases, including uranium and uranium daughter products from milling operations
- liquid and solid chemical and radiological waste discharges to retention ponds
- heat dissipation may cause dense fogging conditions near site
- water availability
- toxic metals - impacts on ground-water quality
- long-term management of uranium mill tailings piles
- accident risks - fires, heavy equipment, tailings pond dike failures
- radon releases

RESOURCES USED:

(Per 10¹² Btu Produced)

TYPE	Tons (a)
uranium ore	4,400
ENERGY	
electricity	113 MWh (a)
natural gas	2.9 x 10 ⁶ scf (a)

LAND

temporarily committed	
undisturbed area	
disturbed area	
permanently committed	
(limited use)	
total	

WATER

Process Water	Acres-Ft. (a)
	8.3

MATERIALS (1)

<u>MATERIALS (1)</u>	
concrete	
total steel & castings	
copper, brass & bronze	
aluminum & castings	
manganese	
chromium	
nickel	
cast iron	
pumps & drivers (1000 HP	

COSTS

<u>COSTS</u>	<u>Dollars (1978)</u>
construction (3)	
manpower	20,000
materials	20,000
equipment	50,000
other construction	20,000
(land rights)	(200)
(speculation during construction)	(6,000)
(interest during construction)	(9,000)
total	<u>150,000</u>
operation & maintenance	120,000

PERSONNEL

construction (2.3 years)	0.7
operation	2.7

RESIDUALS AND PRODUCTS: (2)

(Per 10¹² Btu Produced)

TYPE	Tons
AIR POLLUTANTS	
particulates	2.35 (a)
SO ₂	1.70 (a)
NO _x (40% from natural gas use)	0.33 (a)
hydrocarbons	0.04 (a)
CO	0.01 (a)

WATER POLLUTANTS

<u>WATER POLLUTANTS</u>	<u>Tons (a)</u>
tailings solutions	11,000
other pollutants	NA

SOLID WASTE

<u>SOUTH GASTR</u>	<u>TONS</u>
tailings	4,170

RADIATION

Air	Curies
Ra-222	61.5 (MPC presently reconsidering)
Ra-226	8.3×10^{-4} (a) emission rate) (d)
Th-230	8.3×10^{-4} (a)
U-natural	1.2×10^{-3} (a)

WATER

Curie (a)
U & daughters
8.3×10^{-2}

SOLID WASTE

<u>South East</u>	<u>Curlee</u>
U & daughters	

HEAT

HEAT	Btu's (a)
heat discharged to air	2.9×10^9

ENERGY PRODUCT

<u>ENERGY PRODUCT</u>		Tons (a)
yellowcake (75% U_3O_8)		11.2
U_3O_8 (purified)		8.4

(1) Selected materials and equipment items.

(2) Residuals are a function of the leaching process; sulfuric acid leaching is assumed.

(3) Terms in parentheses are not included in total.

SOURCES (a) U.S. Atomic Energy Commission, Environmental Survey of the Uranium Fuel Cycle (Nash. 1248), 1974.

(b) U.S. Department of Energy, Environmental Development Plan - Uranium Mining, Milling and Conversion.

DOE/ENR-0054, 1979.

(c) U.S. Environmental Protection Agency, Energy from the West - Energy Resource Development Systems Report.

Volume IV: Uranium, EPA-600/7-79-0604, 1979.

(d) U.S. Nuclear Regulatory Commission, Draft Generic Environmental Impact Statement on Uranium Milling.

NUREG-0211, 1979.

(e) Mactel Corporation, Energy Supply Planning Model, 1978.

Uranium Hexafluoride Conversion

ENERGY SYSTEM:

- SIZE**
- 1,500 tons/year
 - supports 27.5 small light water reactors (SLWRs)
 - 8.4 tons produce 10^{12} Btu output
 - 0.8 capacity factor
 - recovery efficiency 100%
 - 20 year lifetime

DESCRIPTION

- Uranium hexafluoride (UF_6) conversion converts the UF_6 (yellowcake) concentrate to a volatile UF_6 compound for enrichment by the gaseous diffusion process. UF_6 conversion can be done by either the dry or wet hydrofluoric process.

COMPONENTS

Dry Hydrofluoric Process

- pre-process handling, weighing, sampling and storage
- reduction-oxidation of Uranium concentrate (U_3O_8) with crushed ammonia (N_2 & H_2) to form UF_4
- hydrofluorination - F_2 reacted with UF_4 to form UF_6 crude product
- solid trap - removal of molybdenum and vanadium fluorides
- distillation - fractional distillation purifies the UF_6 product
- waste ponds

Wet Chemical Solvent Extraction Process

- pre-process handling, weighing, sampling and storage
- digestion in hot nitric acid
- counter-current solvent extraction with TBP in hexane
- reconstruction of uranium as uranyl nitrate solution
- calcination to UO_2
- reduction - UO_2 reduced to UO_2 with crushed ammonia
- hydrofluorination, fluorination, and solid trap same as dry process
- waste ponds

ENVIRONMENTAL CONCERNS

- emissions of off-gases from UF_6 preparation, e.g., fluorides and oxides of nitrogen
- liquid waste from the two waste streams which require holding for future reprocessing or burial
- solid chemical effluents from hydrofluoric process
- release of radon to nearby river and disposal of radioactive sludge
- heat dissipation from UF_6 production
- water availability
- accident risks - fire in solvent extraction, failure or rupture of UF_6 cylinder, raffinate pond failure, uranyl nitrate hexahydrate overpressure failure, and UF_6 release from a storage tank

RESOURCES USED:

(Per 10^{12} Btu Produced)

RESOURCE	Units
FUEL	Tons (a)
yellowcake at 75% U_3O_8	11.2
U_3O_8 (purified)	8.4
ENERGY	
electricity	71 MWh (a)
natural gas	0.83×10^6 scf (a)

LAND

temporarily committed	0.10
undisturbed area	0.09
disturbed area	0.01
permanently committed	0.001
total	0.10

WATER

discharged to air	0.42
discharged to water bodies	2.94
total	3.36

MATERIALS (1)

concrete
total steel & castings
copper, brass & bronze
aluminum & castings
manganese
chromium
nickel
cast iron
pumps & drivers (1000 HP)
heat exchangers (1000 ft ² surface)
non-nuclear pressure vessel

COSTS

construction (2)	Dollars (1976) (c)
major materials	20,000
equipment	9,000
other construction	20,000
(land rights)	10,000
(insurance during construction)	500
(interest during construction)	(5,000)
(working capital)	(15,000)
total	49,000
operation & maintenance	24,000

PERFORMING

construction (3 years)	Man-hours (c)
operation	0.3
	0.4

RESIDUALS AND PRODUCTS:

(Per 10^{12} Btu Produced)

RESIDUALS AND PRODUCTS	Tons (a)
AIR POLLUTANTS	
SO_2	1.30
NO_2	0.46
hydrocarbons	0.04
CO	0.01
F	0.002
WATER POLLUTANTS	
F	1.30
SO_4^{2-}	0.21
NO_3^-	0.01
Cl^-	0.01
Hg^{2+}	0.16
Fe^{3+}	0.07
Pb	0.002

SOLID WASTE

<u>SOLID WASTE</u>	<u>Tons</u>
solid chemical effluents (non-volatile ash con- taining Fe, Ca, Mg, Cu, F)	1.8

RADIATION

<u>Air</u>	<u>Curie</u>
uranium	6.1×10^{-6}
radon and daughters	NA

WASTE

Isotope	Curie (a)
Ra-226	1.4×10^{-4}
Th-230	6.3×10^{-5}
uranium	1.8×10^{-3}

SOLID WASTE

low and intermediate level (buried)	1.6×10^{-2}
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HEAT

<u>heat</u> discharged to air	<u>0.83</u> x 10 ⁶
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ENERGY PRODUCTION

UF_6	8.4
--------	-----

(1) Selected materials and equipment items.
(2) Costs in parentheses are not included in total.

SOURCES: (a) U. S. Atomic Energy Commission, *Environmental Review of the Uranium Fuel Cycle* (Wash. 1249), 1974.
(b) U. S. Department of Energy, *Environmental Development Plan - Uranium Mining, Milling, and Conversion*, DOE/EOP-0034, 1979.
(c) Spectral Corporation, *Energy Supply Planning Model*, 1978.

Uranium Enrichment Gaseous Diffusion

ENERGY SYSTEMS

- SIZE**
- 12,000 tons/year
 - supports 91 model Light Water Reactors (LWRs)
 - 8.4 t/year W_6 produces 1012 Mw output
 - 0.8 capacity factor
 - recovery efficiency 65.4%
 - 20 year lifetime

DESCRIPTION

- Gaseous diffusion enrichment is accomplished by passing the volatile Uranium hexafluoride (UF_6) compound through porous barriers and cascades to produce the product material at percent 23%.

COMPONENTS

- Buildings - process, auxiliary and support, warehouses and storage
- roadways and parking lots
- storage tanks - W_6
- electric switchyards
- steam plant
- recirculation water system
- fire protection water system
- water (chemical treatment) plant
- nitrogen plant
- dry air plant
- tail storage - W_6
- settling neutralization ponds
- waste burial grounds
- fluorine production

ENVIRONMENTAL CONCERNS

- recycle fission products
- air emissions from coal-fired stations for electricity generation, especially particulates, SO_2 , and NO_2
- venting dispersion causing misting and fogging conditions
- emissions of fluorides and its compounds, nitrogen oxides, and sulfur
- liquid effluent containing calcium, chloride, sodium, and sulfate ions
- small quantities of uranium and other radionuclides in process and liquid effluent releases
- water availability
- waste storage
- settling neutralization ponds
- accident risks - fires, explosion, criticality and substantial W_6 releases
- transportation and fission product contamination of process equipment and environmental releases in processing recycle fuel.

RESOURCE USES:

(Per 10¹² Mw Produced)

ITEM	UNIT	Value
FUEL	Tons	6.4
UF_6		
Electricity	MWh	1.3 x 10 ⁸
LAND	Acres	0.04
temporarily committed		0.03
undisturbed area		0.01
permanently committed		0.0
total		0.04

WATER

ITEM	Value
discharged to air (at GWP)	10.7
discharged to water bodies (at GWP)	0.8
discharged to water bodies (at power plants)	1,467

MATERIALS

ITEM	Value
concrete	702,000
total steel & castings	330,000
copper, brass & bronze	11,700
aluminum & castings	7,300
nonferrous	1,800
chromium	2,300
nickel	0,410
cast iron	26,300
steam turbochargers (GWh)	0.24
pumps & drivers (1000 HP)	0.27
axial compressors (1000 HP)	3.80
centrifuge compressors & drivers	0.01
heat exchangers (1000 ft ²)	3.60

COSTS

ITEM	Value
construction (1)	630,000
materials	270,000
equipment	1,070,000
other construction	480,000
land rights	10,000
population during construction	(820,000)
labor cost during construction	(1,270,000)
(working capital)	(480,000)
total	3,470,000
operation & maintenance	350,000

PERSONNEL

ITEM	Value
construction (8 years)	2.8
operation	1.0

EMISSIONS AND PRODUCTS:

(Per 10¹² Mw Produced)

ITEM	Value
AIR POLLUTANTS	
particulates	11.8
SO_2	197.0
NO_2	31.8
hydrocarbons	0.5
CO	1.3
CF_4	0.02
WATER POLLUTANTS	
Ca^{++}	0.5
Cl^-	0.4
Na^+	0.4
SO_4^{--}	0.5
Fe	0.02
NO_3^-	0.12

RADIATION

ITEM	Value
uranium	0.3 x 10 ⁻¹⁵ (a)
radon and daughters	NA
Tr-230	2.3 x 10 ⁻¹⁵ (b)
Pu-239	1.3 x 10 ⁻¹⁰ (b)
Am-241	3.4 x 10 ⁻⁴ (b)
Tr-232	4.6 x 10 ⁻⁴ (b)
Am-243	9.3 x 10 ⁻⁷ (b)
Other fission products	7.0 x 10 ⁻⁴ (b)

WATER

ITEM	Value
uranium	0.3 x 10 ⁻¹⁵
Pu-239	5.1 x 10 ⁻¹² (b)
Am-241	2.3 x 10 ⁻⁹ (b)
Tr-232	5.9 x 10 ⁻⁵ (b)
Am-243	1.3 x 10 ⁻⁷ (b)
Co-137	9.5 x 10 ⁻⁷ (b)
Co-144	9.3 x 10 ⁻⁷ (b)
Tr-230	4.4 x 10 ⁻⁷ (b)

HEAT

ITEM	Value
heat discharged to water	103 x 10 ⁸
heat discharged to air	21 x 10 ⁸

ENERGY PRODUCTION

ITEM	Value
enriched 23% in W_6	3.49
23% in tails	0.01

- (1) Selected materials and equipment items.
 (2) This value represents the amount of U-235 (0.23%) contained in the W_6 depleted tails assay.
 (3) Costs in parentheses are not included in total.

SOURCE(s): U.S. Atomic Energy Commission, Environmental Survey of the Fractional Distillation Cycle (Chab. 1748), 1974.
 (b) U.S. Energy Research and Development Administration, Draft Environmental Statement-Fractional Distillation of U.S. Uranium Enrichment Complex, WASH-1941, 1975.
 (c) Bacthal Corporation, Energy Supply and Planning Model, 1978.

Uranium Enrichment Gas Centrifuge

ENERGY SYSTEM:

- SIZE • 10,000 tons/year
- operates 75 small Light Water Reactors (LWRs)
- 8.4 tons W_6 produce 10^{12} Btu output
- 0.8 capacity factor
- recovery efficiency 45.4%
- 20 year lifetime

DESCRIPTION

- Gas centrifuge enrichment is similar to gaseous diffusion except for the substitution of centrifuges for the system of compressors and barrier materials.

COMPONENTS

- production facilities
- feed, product, and tails withdrawal systems
- recycle/assembly plant
- facility for equipment decontamination and uranium recovery
- steam plant
- miscellaneous support facilities
- laboratories
- air plant
- recirculating water system
- auxiliary water system
- firewater system
- sanitary sewage system
- storm drainage
- holding ponds
- burial grounds
- heat dissipation system
- tail enrichment facility

ENVIRONMENTAL CONCERNS

- gaseous emissions from coal-fired station for heating, process steam and electrical power generation, i.e., particulates, CO , water vapor, SO_2 , NO_2
- small quantities of CO , HC , and aldehydes from stack effluent
- fly ash and slurry discharges to holding ponds
- waste from uranium recovery facility discharged to holding pond
- radioactive emissions
- water availability
- accident risks - critically accidents, W_6 releases, fires, and centrifuge failure

RESOURCES USED: (Per 10^{12} Btu Produced)

FUEL	Tons ^(a)
W_6	8.4
ENERGY	
coal (heating and process steam)	36.7 tons ^(b)
gasoline and diesel	
fuel	114 million ^(b)
electricity	1.1×10^5 kWh ^(b)
LAND	Acres ^(b)
temporarily committed to plant	0.45
disturbed area	0.25
undeveloped area committed to landfill	0.20
disposal (year 2000)	
uranium-contaminated material	0.01
uncontaminated material	0.001
total	0.44

WATER	Acres-Ft. ^(b)
discharged to air	
cooling towers	0.44
steam plant	0.05
discharged to water	
enrichment plant	
operations	0.91
sanitary waste	0.11
total required	1.52
(additional reserve for fire protection)	(0.005)

MATERIALS ⁽¹⁾	Tons ^(a)
concrete ⁽²⁾	359.00
steel ⁽³⁾	151.00
aluminum	14.00
copper	1.70
zinc	0.12
transformer cooling oil	0.18
sewing materials ⁽⁴⁾	0.70
miscellaneous metal products	0.43

COSTS	Dollars (1975) ^(b)
construction	
centrifuge plant	1,900,000
(land rights)	(444)
rotor fabrication plant	63,300
(land rights)	(32)
total	1,963,300
operation & maintenance	360,000

PERSONNEL	Man-years ^(b)
construction (7 years) ⁽⁴⁾	2.8
operation	1.0

RESIDUALS AND PRODUCTS: (Per 10^{12} Btu Produced)

ATE POLLUTANTS ⁽⁵⁾	Tons ^(b)
particulates	0.02
SO_2	0.44
NO_2	0.57
hydrocarbons	negligible
CO	0.01

WATER POLLUTANTS ⁽⁴⁾	Tons ^(b)
condensate	2.03
water	2.03
HNO_3	negligible
$Al(OH)_3$	trace

ACTINIDE WASTE	Tons ^(b)
water	0.31
HNO_3	0.05
$Al(OH)_3$	0.04
F^-	negligible
U	negligible

Nonrecoverable Gases	Tons ^(b)
SiH_4	0.001
H_2	trace

RADIATION

Air	Curies ^(b)
uranium (total isotopes)	3.1×10^{-5}
(since no recycled feed material will be processed by gas centrifuge, values for Pu-239, Pu-237, Pu-106, Pu-104, Pu-95, Ce-137, Ce-144, and Tc-99 are shown only for gaseous diffusion)	

Water	Curies ^(b)
uranium (total isotopes)	3.3×10^{-4}
(since no recycle feed material will be processed by gas centrifuge, values for Pu-239, Pu-237, Pu-106, Pu-104, Pu-95, Ce-137, Ce-144, and Tc-99 are shown only for gaseous diffusion)	

HEAT	Btu
heat dissipated from steam plant	0.2×10^9

ENERGY PRODUCT	Tons ^(c)
enriched $235g$ in W_6	3.49

BY-PRODUCT ⁽⁷⁾	Tons ^(c)
$235g$ in tails	0.01

(1) More materials data taken from ECHA 1,343 reported for 10 plants, p. 8.1-4.

(2) Selected materials and equipment items.

(3) Materials for and included for auxiliary rotor fabrication plant.

(4) This total includes 0.7 man-years per year for construction of the rotor fabrication plant which requires about 4.75 years for design and construction.

(5) From coal-fired plant.

(6) From uranium recovery facility.

(7) This value represents the amount of U-235 (0.25%) contained in the depleted W_6 tails assay.

SOURCE: (a) U.S. Energy Research and Development Administration, Draft Environmental Statement-Portsmouth Gaseous Diffusion Plant Expansion, Pibston, Ohio, ECHA-1549, 1976.

(b) U.S. Energy Research and Development Administration, Draft Environmental Statement-Expansion of U.S. Uranium Enrichment Capacity, ECHA-1543, 1975.

(c) U.S. Atomic Energy Commission, Environmental Survey of the Uranium Fuel Cycle (EACH-1248), 1974.

Fuel Fabrication Plant

ENERGY SYSTEM:

- SIZE**
- 990 tons/year supports 26 model light water reactors (LWRs)
 - 3.45 tons produce 10^{15} Btu output
 - 0.8 capacity factor
 - conversion efficiency 100%
 - 20 year lifetime

DESCRIPTION

- Fuel fabrication is accomplished by chemical conversion of U_3O_8 to UO_2 and mechanical processing including pallet production and fuel element fabrication loaded in stainless or stainless steel tubes, fitted with end caps and welded.

COMPONENTS

UO₂ Powder Processing

- Vaporization of U_3O_8 in steam or electrically heated cabinet
- hydrolysis - reacting U_3O_8 with H_2O to form UO_2 oxides
- precipitation - ammonium hydroxide to convert UO_2 to ammonium diuranate (ADU)
- centrifuge or filtration - concentrate
- ADU slurries
- calcination - ADU is calcined by heating
- reduction - ADU reduced to UO_2 powder in a reducing atmosphere (hydrogen)

Mechanical Processing

- pretreatment of UO_2 powder by comminution, compaction and granulation to obtain desired particle size
- pelletizing
- distorting of pellets in a reducing atmosphere
- grinding to finished dimensions
- washing and drying the pellets
- loading pellets into fuel rods and welding the end caps
- assemble fuel rods to form finished fuel elements

Scrap Recovery/Off-Specification Material

- dissolution of uranium in nitric acid to form uranyl nitrate
- purification of uranium through solvent extraction
- reconversion of uranium to return to UO_2 production

ENVIRONMENTAL CONCERNS

- releases from coal-fired power plant for electricity generation
- fluorides emission from fabrication plant
- nitrogen compounds in liquid effluents from H_2O in UO_2 production and nitric acid recovery of scrap
- heat dissipation into environment
- radioactive contaminated Co_2 (solid waste)
- Plutonium waste
- accident risks - rupture of UO_2 cylinder releasing U and WF_6 furnace effluent releasing U, and criticality accident

- (1) Selected material and equipment items.
(2) These values represent no Pu and Pu recycle, lot and 2nd, respectively. Costs in parentheses are not included in total.
(3) Three years are required if there is no Pu recycle, two years if there is Pu recycle.

DOUGHERTY, G. H. Atomic Energy Commission, Environmental Survey of the Uranium Fuel Cycle (Tech. 1246), 1975. Chemical Corporation, Energy Supply Planning Model, 1978.

RESOURCES USED:

(Per 10^{15} Btu Produced)

ITEM	Yr/yr
enriched $235g$ in UO_2	5.49
ENERGY	(a)
electricity	71 kWh
natural gas	1.5×10^5 acf/a
LAND	(a)
temporarily committed	1.01
undisturbed area	0.01
disturbed area	0.002
permanently committed	0.0
total	0.01

WATER	Acres-ft (a)
discharged to water	0.67

MATERIALS (1)

ITEM	Yr/yr (b)
concrete	74.70 - 444.0
total steel & castings	12.90 - 45.90
copper, brass & bronze	0.15 - 5.20
aluminum & castings	0.27 - 1.43
magnesium	0.08 - 0.21
chromium	0.10 - 0.13
nickel	0.02 - 0.03
cast iron	0.49 - 0.90
steam turbines (1000 HP)	0.01 - 0.00
pumps & drivers (1000 HP)	0.01 - 0.04
heat exchangers (1000 ft ²)	0.00 - 0.03

COSTS

CONSTRUCTION	Dollars (1978) (2) (b)
manpower	60,000 - 220,000
materials	10,000 - 40,000
equipment	80,000 - 240,000
other construction	20,000 - 60,000
(land rights)	(400 - 1,000)
(location during construction)	(20,000 - 30,000)
(interest during construction)	(30,000 - 50,000)
(working capital)	(30,000 - 100,000)
total	170,000 - 600,000
operation & maintenance	180,000 - 260,000

PERSONNEL

CONSTRUCTION (3rd years)	Man/yr (a)
operation	0.7 - 1.4 (3)
	1.6 - 3.4

RESIDUALS AND PRODUCTS:

(Per 10^{15} Btu Produced)

AIR POLLUTANTS	Yr/yr (a)
SO_2	1.10
NO_2	0.28
hydrocarbons	negligible
CO	0.01
Pb	negligible

WATER POLLUTANTS	Yr/yr (a)
H as H_2	0.46
N as NO_3	1.10
fluoride	0.19

ACID WASTE	Yr/yr (a)
CaF_2	1.20

RADIATION	Curies (a)
gamma	8.3×10^{-6}
uranium	

Liquids	Curies (a)
uranium	8.3×10^{-6}
$Th-234$	4.2×10^{-6}

SOLID WASTE	Curies (a)
uranium (waste)	9.4×10^{-3}

HEAT	Btu (a)
heat dissipated	0.4×10^9

ENERGY PRODUCT	Yr/yr (a)
uranium (UO_2) fuel elements	1.6

Light Water Reactor Nonradiological Effluents

ENERGY SYSTEM

- 1,000 Mw Light Water Reactor (LWR)
- produces 21×10^{12} Btu
- 0.7 capacity factor
- conversion efficiency 33%
- 40 year lifetime

DESCRIPTION

- Light Water Reactors (LWR) consist of two types: pressurised-water reactor (PWR) which heats water without allowing it to boil and the boiling water reactor (BWR).

CONCLUSIONS

- containment structure
- reactor vessel
- fuel assemblies within reactor core
- steam generator
- turbine generator
- cooling water condenser
- liquid waste system
- cooling towers
- PWR has a dual cooling system using steam generators
- has only a primary cooling system
- spent fuel storage
- waste treatment systems
- auxiliary ventilation control systems
- engineered safety features

ENVIRONMENTAL CONCERNS

- airborne chemical
 - cooling tower drift release
 - chemical effluent release from power installation (CR-83, CR-87, CR-88, CR-3, 1-131, 10-133)
- liquid chemical effluents from cooling systems
 - liquid radioactive effluents from power generation (CR-7, CR-10, CR-11, CR-12, CR-134, CR-137, 1-131, 10-34, 10-59, 10-144, 10-146)
 - use
 - availability of water
 - spent fuel transport, storage, and disposition
 - thermal effluents
 - cooling water chemical effluents
 - transmission line (acidic effluent on wildlife systems)
 - soephene (cooling towers and transmission lines)
 - decontamination and decommissioning at end of plant useful life
 - radioactive waste (low-level, red action, less of coolant, steam generator tube rupture, other transients, failure of fuel element structure)

*These consist of a 2:1 mix of Fills and HMA
*Selected materials and equipment items

Note: Values reported in ARAR were derived from Bissells, C.A., Strategic Environmental Assessment Program: Radiation Baseline, NTP-4511, 1973.

RESOURCES USED:
(Per 10¹² Btu Produced)

	1981 (a)
FUEL	7.8
uranium (20%) fuel elements	
	Acres (b)
	3.5
LAND	
unusually committed	
	Acre-ft. (b)
WATER	720
losses from evaporation,	
drift	73
discharged to water bodies	
	Tonnes (c)
MATERIALS	24,500.00
concrete	3,450.00
total steel & castings	104.00
brass & bronze	31.30
aluminum & castings	18.00
manganese	20.00
chromium	3.50
nickel	36.29
cast iron	47.00
steel turbochargers (50%)	1.00
steam turbines (1000 hp)	4.00
pump & drivers (1000 hp)	4.00
cond. submersibles (1000 ft.)	17.00
nuclear state supply system	

COSTS **Dollars (1978) (c)**

construction	
pumpout	8,080,000
materials	3,130,000
equipment	7,980,000
other construction	6,280,000
(land rights)	(130,000)
general plant	780,000
depreciation during	
construction	(11,990,000)
(interest during	
construction)	(13,330,000)
working capital)	(6,130,000)
total	26,270,000
operation & maintenance	710,000
present value	Net Present Value (c)
construction (9 years)	29.6
operation	3.7

RESIDUALS AND PRODUCTS:
(Per 10¹² Btu Produced)

AIR POLLUTANTS	Time (h)
particulates	0.8×10^{-1}
chromates	1.7×10^{-1}
sine	3.7×10^{-3}
chlorides	

<u>WATER POLLUTANTS</u>	<u>Time (h)</u>
BOD	1.0×10^{-1}
chlorine	1.2
phosphate	1.8
boron	14.4
chromates	1.0×10^{-1}
acids	3.6
residue	2.9

SOLID WASTE

<u>SOLID WASTE</u>	<u>Year</u>
total	NA

RADIATION (weighted 2:1 per hour) (b)

<u>Air</u>	<u>Curie</u>
Kr-65	3.6
I-131	4.0×10^{-3}
Xe-133	2.11×10^3
fission products	6.0×10^2
R-3	1.26
Kr-67	NA
Kr-68	NA
	$2.0 \times 10^{11}(\text{yr})$

	Conc'n (N)
Water	10.12
H-3	1.5 x 10 ⁻⁵
Co-60	2.1 x 10 ⁻⁵
Sr-90	5.95 x 10 ⁻⁶
Mn-106	3.27 x 10 ⁻⁶
I-131	1.26 x 10 ⁻⁶
Co-134	9.23 x 10 ⁻⁶
Co-137	1.5 x 10 ⁻⁶
Co-144	6.33 x 10 ⁻⁶
fission products	NA
Hg-99	NA
Te-132	NA

SOLID WASTE

low level	12.3
high level	18.5

BEAT

heat dissipated	2×10^{-10}
<u>ENERGY PRODUCT</u>	<u>kg-hrs</u>
electricity	2.93×10

SOURCE: (a) U.S. Atomic Energy Commission, Environmental Survey of the Uranium Fuel Cycle (Wash., 1948), 1974.
 (b) The MITRE Corporation, Annual Environmental Analysis Report (AEAR), 1977.
 (c) Bechtel Corporation, Nuclear Supply Planning Model, 1978.
 (d) U.S. Environmental Protection Agency, Assessment of Carbon-14 Control Technology and Costs for the LWR Fuel Cycle, EPA 320/4-77-013, 1977.

Light Water Reactor Radiological Effluents

Radiation Type	FWP Curies	SWP Curies	Air Curies	FWP Curies	SWP Curies	Air Curies	FWP Curies	SWP Curies
Ar-37	6.83×10^{-4}	NA	Co-58	8.90×10^{-4}	1.51×10^{-3}	Na-48	1.91×10^{-3}	1.52×10^{-3}
Ar-41	6.04×10^{-4}	3.25×10^{-3}	Co-60	2.66×10^{-3}	1.54×10^{-3}	Na-59	3.16×10^{-3}	3.09×10^{-3}
Kr-85m	2.37×10^{-3}	9.60×10^{-3}	Rn-89	3.53×10^{-3}	1.17×10^{-2}	Fe-59m	7.99×10^{-3}	3.10×10^{-3}
Kr-85	3.90	1.64×10^2	Rn-90	6.31×10^{-3}	2.48×10^{-4}	Co-139	8.32×10^{-3}	NA
Kr-85m	2.77	5.31×10^2	Rn-91	5.78×10^{-3}	NA	Co-141	2.18×10^{-2}	3.04×10^{-4}
Kr-87	7.06×10^{-4}	1.57×10^2	Rn-95	5.41×10^{-3}	1.91×10^{-4}	Co-144	2.26×10^{-2}	1.14×10^{-3}
Kr-88	2.70	1.54×10^2	W-95	5.41×10^{-3}	9.28×10^{-3}	Ag-108m	3.68×10^{-2}	NA
Xe-133m	5.77×10^{-3}	1.50×10^2	W-97	8.17×10^{-3}	NA	Ag-110m	1.29×10^{-2}	1.89×10^{-4}
Xe-133	4.88×10^{-3}	1.52×10^2	Co-134	4.04×10^{-3}	2.34×10^{-3}	Ag-113m	4.54×10^{-2}	1.66×10^{-3}
Xe-133m	6.85	1.72×10^2	Co-136	7.81×10^{-3}	2.47×10^{-3}	Na-24	2.29×10^{-2}	5.92×10^{-3}
Xe-133	4.30×10^3	2.09×10^2	Co-137	2.31×10^{-3}	5.43×10^{-4}	Rn-108	7.36×10^{-3}	7.47×10^{-3}
Xe-133m	4.21×10^{-3}	3.62×10^2	Co-138	1.11×10^{-3}	NA	Rn-112m	9.33×10^{-2}	NA
Xe-137	1.14×10^{-3}	NA	Na-131	1.33×10^{-2}	NA	Co-109	1.66×10^{-3}	NA
Xe-137	2.87×10^{-3}	2.87×10^{-3}	Na-133	1.53×10^{-2}	NA	Co-115	5.41×10^{-3}	NA
I-131	2.28×10^{-3}	5.56×10^{-2}	Na-136	6.61×10^{-2}	NA	Co-64	5.81×10^{-4}	NA
I-132	2.14×10^{-3}	NA	Na-140	7.80×10^{-3}	1.87×10^{-2}	Bi-45	1.47×10^{-6}	NA
I-133	2.08×10^{-3}	3.31×10^{-1}	La-140	7.80×10^{-3}	2.23×10^{-3}	Th-132	1.89×10^{-2}	NA
I-134	4.73×10^{-4}	NA	Bi-1	7.62	6.27×10^{-4}	Bi-124	2.84×10^{-3}	NA
I-135	7.42×10^{-3}	3.59×10^{-2}	Co-51	7.38×10^{-4}	4.75×10^{-4}	Fe-59	NA	1.77×10^{-4}
Rn-82	4.01×10^{-3}	NA	Na-54	6.78×10^{-2}	2.54×10^{-3}	Na-45	NA	6.06×10^{-3}
Co-58	1.44×10^{-1}	1.0×10^{-1}	Na-56	3.13×10^{-3}	NA	Ag-76	NA	1.47×10^{-3}
Co-57	6.03×10^{-3}	NA						

Water Curies	SWP Curies	Water Curies	FWP Curies	SWP Curies	Water Curies	FWP Curies	SWP Curies
Ar-41	1.17×10^{-4}	NA	Na-45	6.71×10^{-4}	3.39×10^{-3}	Co-139	4.06×10^{-3}
Kr-85	2.18×10^{-3}	NA	Co-75	1.10×10^{-3}	NA	Co-141	1.28×10^{-3}
Kr-85m	6.13×10^{-3}	NA	Na-45	3.09×10^{-3}	NA	Co-144	1.40×10^{-3}
Kr-87	1.12×10^{-3}	NA	Rn-89	1.91×10^{-3}	1.63×10^{-3}	Bi-107	1.41×10^{-4}
Kr-88	3.38×10^{-3}	NA	Rn-90	4.43×10^{-3}	4.09×10^{-3}	W-139	1.67×10^{-4}
Xe-133m	6.80×10^{-3}	NA	Rn-91	1.20×10^{-3}	1.37×10^{-3}	Bi-3	2.11×10^{-4}
Xe-133	1.08	9.52×10^{-3}	Rn-92	2.84×10^{-3}	NA	Co-16	7.33×10^{-7}
Xe-133m	6.72×10^{-3}	NA	Bi-93	1.07×10^{-3}	1.80×10^{-3}	Bi-45	4.13×10^{-4}
Xe-133	5.18×10^{-4}	1.44×10^{-2}	Rn-95	1.29×10^{-3}	6.41×10^{-4}	W-88	6.64×10^{-4}
Xe-133m	7.51×10^{-2}	NA	Co-97	3.94×10^{-3}	NA	Co-99m	9.37×10^{-4}
I-131	4.46×10^{-3}	1.29×10^{-3}	Rn-97	2.73×10^{-3}	NA	Co-109	1.39×10^{-3}
I-132	4.46×10^{-3}	5.28×10^{-3}	Na-99	4.23×10^{-3}	4.44×10^{-3}	Co-115	9.37×10^{-3}
I-133	2.17×10^{-3}	8.54×10^{-3}	W-105	2.40×10^{-3}	2.60×10^{-4}	Co-115m	1.13×10^{-3}
I-134	3.80×10^{-2}	NA	W-106	1.72×10^{-3}	NA	Y-92	2.66×10^{-6}
I-135	1.10×10^{-3}	1.39×10^{-3}	Ag-108m	5.60×10^{-7}	NA	Bi-113m	1.13×10^{-3}
Bi-7	1.01×10^{-4}	NA	Ag-110m	5.28×10^{-3}	3.23×10^{-3}	Bi-113	5.34×10^{-4}
Co-57	2.88×10^{-2}	NA	Co-134	4.08×10^{-2}	4.75×10^{-3}	Bi-117m	4.34×10^{-4}
Co-58	6.51×10^{-2}	2.22×10^{-3}	Co-136	5.38×10^{-4}	1.07×10^{-2}	Bi-123m	3.41×10^{-6}
Co-60	2.28×10^{-2}	1.50×10^{-2}	Co-137	5.28×10^{-3}	6.91×10^{-2}	Bi-198	7.57×10^{-6}
Fe-59	1.17×10^{-2}	2.83×10^{-3}	Co-138	8.27×10^{-7}	NA	Bi-45	1.47×10^{-3}
Na-24	5.97×10^{-2}	1.44×10^{-2}	Na-133	6.27×10^{-4}	NA	Bi-124	7.38×10^{-2}
Co-51	1.39×10^{-3}	2.54×10^{-2}	Na-139	7.72×10^{-4}	NA	P-18	1.14×10^{-2}
Na-54	6.91×10^{-3}	1.43×10^{-2}	Na-140	1.07×10^{-3}	5.68×10^{-3}	Bi-31	3.42×10^{-4}
Na-56	1.08×10^{-3}	1.52×10^{-4}	La-140	9.93×10^{-4}	8.23×10^{-3}	Ag-76	NA
Co-44	2.02×10^{-4}	NA	Co-134	4.09×10^{-3}	NA	Y-90	NA

Solid Waste
Curies
Total 48.7 79.0

*These results represent a weighted average for FWPs in operation during 1976.
Representative reactors include: Belconn and Wilson-Diamonds 1, 2, 3, 4, 5,
Nashville, and Three Mile Island 1; Combustion Engineering-Oak Ridge, Clifton,
Millstone Point 1, Palisades, and Fort Calhoun; and Westinghouse-Indian Point,
Derry 1 & 2, York, and Zion 1 & 2.

**These results represent a weighted average for SWPs in operation during 1976.
Representative reactors include: General Electric - Browns Ferry 1, 2 & 3,
Braidon 2 & 3, Millstone Point 1, Peach Bottom 2 & 3, and Quad Cities 1 & 2.

SOURCE: U.S. Nuclear Regulatory Commission, Radiological Materials Released From
Nuclear Power Plants (1976), NUREG-0197, 1977.
U.S. Environmental Protection Agency, Assessment of Carbon-14 Control Technology and
Costs for the LWR Fuel Cycle, EPA 560/4-77-013, 1977.

High Temperature Gas Reactor

ENERGY SYSTEM:

- size • 1,160 Mw High Temperature Gas Reactor (HTGR) plant
- pressure 24.3 x 10³ Pa
- 0.7 capacity factor
- conversion efficiency 38%
- 30 year lifetime

DESCRIPTION:

- High Temperature Gas Reactor (HTGR)
- use helium as a coolant and heat transfer medium, instead of water or steam
- used in the High Temperature Reactor (HTR). The use of helium allows high efficiencies of 40 percent. The HTGR uses Th-232, U-235, and U-238 fuels.

COMPONENTS:

- containment structure
- fuel microsphere contained in reactor core
- helium circulator
- steam generator
- preheated concrete reactor vessel (PCRV)
- turbine generator
- water cooling condenser
- cooling towers
- helium purification system
- gaseous waste system
- liquid waste system
- gas purification system

ENVIRONMENTAL CONCERNS:

- reactor core components contaminated with graphite dust film of "placenta"
- radioactivity
- unattended control rod drive failure
- gas plant refueling and tritium diffusive data secondary coolant system
- airborne release of small quantities of fission products and activation gases, helium (mostly radon), tritium, and particulate material
- water availability and quality
- thermal discharges causing fogging and icing - site dependent
- transmission lines
- liquid radioactive waste discharge
- accident risks - radon gas system failures, fission products released from primary to secondary system, refueling, spent fuel handling, loss of coolant

RESOURCES USED:

Item	Unit	Value
fuel (1)	kg	0.0174
U-235	kg	0.115
thorium	kg	0.172
electricity	kWh	7.3

Item	Unit	Value
land	Acres	1.1
plant site	Acres	0.2
radiated area	Acres	1.8
transmission line	mi	0.2
undisturbed area	Acres	4.0
plant site	Acres	7.3
total	Acres	14.4

Item	Unit	Value
water	kg	1000
input to process	kg	465
discharged	kg	535
- to air	kg	535
- to water bodies	kg	0
materials	kg	17,000.00
concrete	kg	5,340.00
steel and castings	kg	82.40
copper, brass & bronze	kg	27.40
aluminum & castings	kg	36.00
manganese	kg	36.20
chromium	kg	5.00
nickel	kg	126.00
cast iron	kg	47.00
steam turbine generator (MW)	kg	1.00
steam turbine (1000 HP)	kg	3.10
pumps & drivers (1000 HP)	kg	0.20
heat exchangers (1000 ft ²)	kg	47.00
nuclear steam supply system	kg	47.00

Item	Unit	Value
costs	\$	7,800,000
construction	\$	2,500,000
materials	\$	10,570,000
equipment	\$	4,570,000
other construction	\$	(140,000)
land rights	\$	760,000
general plant	\$	(13,000,000)
construction during	\$	(14,490,000)
construction	\$	(4,490,000)
(working capital)	\$	28,490,000
total	\$	550,000
operation & maintenance	\$	550,000

Item	Unit	Value
personnel	man	28.7
construction (9 years)	man	4.4
operation	man	4.4

RESOURCES AND PRODUCTS:

Item	Unit	Value
air pollutants	kg	340 x 10 ³
water vapor	kg	340 x 10 ³
other	kg	340 x 10 ³
water pollutants	kg	13.1
air	kg	7.0
CO ₂	kg	16.3
NO _x	kg	37.2
SO ₂	kg	0.1
HCN	kg	0.6
CO	kg	0.08
PO ₄	kg	0.06
SiO ₂	kg	0.04
total	kg	110.2
solid waste	kg	340 x 10 ³
total	kg	340 x 10 ³
radiation	Curie	1.2
air	Curie	1.2
water	Curie	1.2
soil	Curie	1.2
food	Curie	1.2
building	Curie	1.2
transportation	Curie	1.2
communication	Curie	1.2
energy	Curie	1.2
materials	Curie	1.2
equipment	Curie	1.2
other	Curie	1.2
total	Curie	1.2

- (1) Initial fuel loading only Th-232 and U-235. The Th-232 in the reactor converts to U-233 which is recycled for use as fuel.
- (2) Selected materials and equipment items.
- (3) Weight not available.

- SOURCES: (a) University of Oklahoma, *Nuclear Alternatives: A Comparative Analysis*, 1975.
 (b) U.S. Nuclear Regulatory Commission, *Final Environmental Statement - Fort St. Vrain Generating Station Units 1 and 2*, 1975.
 (c) Nuclear Corporation, *Nuclear Supply Planning Model*, 1978.

Light Water Breeder Reactor

ENERGY SYSTEM:

- SIZE**
- 1,000 Mw Light Water Breeder Reactor (LWBR)
 - produces 21 x 10¹² Btu/year
 - 0.7 capacity factor
 - conversion efficiency 30%
 - 30 year lifetime

DESCRIPTION:

- Light Water Breeder Reactor (LWBR) employs a technology similar to Light Water Reactor (LWR), it also breeds additional nuclear fuel using thorium oxide.

COMPONENTS:

- containment structure
- reactor vessel
- pressurizer
- boilers
- steam generator
- turbine generator
- reactor coolant loops
- LWBR reactor core
- gaseous waste system
- liquid waste system
- plant ventilation control systems
- fuel handling system components

ENVIRONMENTAL CONSEQUENCES:

- emissions of airborne chemical and radioactive effluents to the atmosphere
- emissions of liquid chemical and radioactive effluents
- heat dissipation
- availability of water
- land used
- thermal impacts
- accident risks - radioactive system failure, fission products released from primary to secondary system, refueling, spent fuel handling, loss of coolant, steam generator tube rupture and other transients.

RESOURCES USED: (Per 10¹² Btu Produced)

FUEL (Frothwater)

U-235 0.2
U-238 1.6
thorium 3.7

FUEL (Breeder)

uranium-fissile 0.1
other uranium⁽¹⁾ 0.85
thorium (2) 4.9

SPENT FUEL

1,905

LAND

temporarily committed 23.3
undisturbed area 21.0
disturbed area 1.5
permanently committed 0.1
total 23.6

WATER

discharged to air 720
discharged to water bodies 72

MATERIALS

concrete 26,200
total steel & castings 3,430
copper, brass & bronze 104
aluminum & castings 31.3
magnesium 18.0
chromium 20.8
nickel 3.5
cast iron 39.2
steam turbine generator (MWs) 47.0
steam turbines (1000 HP) 1.0
pumps & drivers (1000 HP) 4.8
heat exchangers (1000 ft²) 14.8
nuclear steam supply systems 47.8

COSTS

construction
manpower 8,000,000
materials 3,230,000
equipment 7,980,000
other construction 6,280,000
(land rights) (150,000)
general plant 700,000
(escalation during construction) (11,990,000)
(interest during construction) (15,550,000)
(working capital) (4,130,000)
total 26,270,000
operation & maintenance 710,000

FINANCIAL

construction (9 years) 27.5
operation 5.7

RESOURCES AND PRODUCTS: (Per 10¹² Btu Produced)

AIR POLLUTANTS

particulates 0.01
SO₂ 0.04
NO_x 0.04
hydrocarbons negligible
CO negligible
aldehydes negligible

WATER POLLUTANTS

sulfate and sulfide 27.5
chloride 0.04

SOLID WASTE

total NA

EMISSIONS

CO₂ (a) 32.4(1)
CH₄ 0.3(1)
C-14 0.3(1)
Kr-85 37.3(1)
iodine (all isotopes) 4.8 x 10⁻³
other fission products 147.4(1)

WATER

B-1

HEAT

heat dissipated 2 x 10¹³

ENERGY PRODUCTION

electricity 2.93 x 10⁶

(1) These values represent the upper limit when a range of two values was reported.

(2) Estimates based on light water reactor costs, selected materials and equipment items, and manpower. Construction cost items in parentheses are not included in total.

(3) Uranium isotopes given from irradiation of uranium 235.

(4) Does not include small amount of thorium from recycle of reflector. This is estimated to be less than 0.33 to 0.13 ton thorium per year.

SOURCE: U.S. Energy Research and Development Administration, *Final Environmental Statement-Light Water Breeder Reactor Project*, Vols. 1-5, ERDA-1541.

(b) Bechtel Corporation, *Nuclear Supply Financing Model*, 1978.

Coal

APPENDIX A

Coal - Fired Power Plant (Eastern Coal)

Environmental Characterization Information Report

Draft
June 1980

William G. Wilson: Technical Project Officer

U.S. Department of Energy
Assistant Secretary for Environment
Office of Environmental Assessments

FOREWORD

This Environmental Characterization Information Report (ECIR) is a synthesis of environmental data and information relevant to a coal-fired power plant that burns eastern coal. It is prototypical of a set of ECIRs that will be developed for a range of fossil, solar, geothermal, nuclear, and conservation energy systems. The ECIRs are designed to have several related purposes: to communicate to all potential users environmental data and information characteristic of an energy system; to present an organized data and information base for application in manual and computer-based analytical systems; and to provide the medium for facilitating development, maintenance, and critical review of the data and information base. The set of ECIRs is designed to replace the general technical backup volumes formerly supplied with "Environmental Data Energy Technology Characterizations," Summary, January 1980.

Responsibility for the contents and development of an ECIR is assigned to individual technology specialists in the Technology Assessments Division. In this endeavor, we expect to draw upon the technical support and assistance of qualified experts familiar with the energy systems. Technical comments regarding this ECIR should be directed to Mr. William G. Wilson, (301) 353-4414. Suggestions or recommendations for improving the ECIR concept should be addressed to me.

Dario R. Monti
Director, Technology Assessments
Division
Office of Technology Impacts

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Surface Coal Mining - Eastern

ENERGY SYSTEM:

- SITE**
- 20-year mine life
 - 4 million tons per year
 - 102.8×10^6 lbs per year equivalent
 - Eastern area mine, Northern Appalachian district

DESCRIPTION

• is the East, modified area mining is generally used in areas where the terrain is gentle (5° to 10° slope) and the overburden does not exceed about 100 feet. Typically, the thickness of the coal bed averages six feet and the efficiency of removal is about 80 percent (in terms of lbs recovered). Blasting with light charges is frequently needed to improve the mining. Overburden from each successive cut is placed in the previous one. Grading to approximate the original land form is undertaken. Topsoil is replaced and revegetation is begun. Coal is transported to an offsite coal preparation plant.

COMPONENTS

Component	Quantity
• power shovels	2
• trucks	7
• front end loaders	2
• scrapers	4
• coal shovel	2
• drilling equipment	4
• graders	2
• cable hauler & reel	2
• bulldozers	8

ENVIRONMENTAL CONCERNS

- aesthetics
- solids mine drainage contamination of surface and groundwater
- blasting damage and noise pollution
- vehicular emissions
- fugitive dust
- erosion
- altered land use

RESOURCES USED: (Per 10^6 lbs Produced)

RESOURCE DEPLETION

in-place coal	48,438 tons
energy content	12,850 Btu/lb

COAL ANALYSIS

% (by weight)	
moisture	1.7
volatile matter	34.1
fixed carbon	32.4
ash	9.6
sulfur	2.1
nitrogen	1.1

ENERGY

diesel fuel	4.0×10^6 Btu
electricity	5.8×10^6 kWh

LAND

fixed	Acres
incremental	0.3
	6.1

WATER

consumption	Acres-Foot
	1.7

COSTS

construction	Dollars (1977)
total construction cost	1.24×10^6
other investment and fees	0.68×10^6
operation	
general mining cost	0.46×10^6
reclamation and sediment control	3×10^6

PERSONNEL

construction	Workers
non-manual, technical	1.0
non-manual, non-technical	0.2
manual	4.7
operation	
non-manual, technical	0.8
non-manual, non-technical	1.1
manual	2.4

RESIDUALS (Per 10^{12} lbs Produced)

AIR POLLUTANTS

particulates(T)	0.06	0.02
SO ₂	0.1	0.1
NO ₂	1.3	1.3
hydrocarbons	0.2	0.2
CO	0.9	0.9

WATER POLLUTANTS

Total Dissolved Solids	35.6	20.8
Iron	0.4	0.0004
Manganese	0.4	0.1
Aluminum	0.6	0.02
Zinc	0.02	0.002
Nickel	0.006	0.002
Total Suspended Solids	4.8	0.4
Iron	0.02	0.004
Ammonia	0.04	0.02
Sulfate	16.1	19.3

SOLID WASTE (2)

overburden removal	435	0
runoff treatment	390	0

ENERGY PRODUCTION

raw coal - 18,910 tons

- (1) Assume a 50% reduction in fugitive dust emissions through dust suppression.
(2) Assume all solid waste is returned to mining pits.

SOURCES: The MINE Corporation, Annual Environmental Analysis Report, 1977.
University of Oklahoma, Energy Alternatives: A Comparative Analysis, 1975.
EPA, Basic Environmental Data Book, Volume IV, 1978.
Mittman Associates, Inc., Environmental Impacts, Efficiency, and Cost of Energy Supply and Use, Volume I, 1974.
Bechtel Corporation, Energy Supply Planning Model, 1979.
Bureau of Mines, Basic Estimated Capital Investment and Operating Costs for Coal Strip Mines, 1976.
Energy and Environmental Analysis, Coal and Profitability, 1979.
Bureau of Land Management, Federal Coal Management Program, Final Environmental Statement, 1979.

Surface Coal Mining - Western

ENERGY SYSTEM:

- SIZE** • 6 million tons per year
 • 1.1×10^{14} Btu per year equivalent
 • 30 year mine life
 • Western area mine, Powder River Basin

DESCRIPTION

• In Wyoming and Montana, the two states which will account for most of the increase in production in the West, area strip mining is the dominant surface mining technique. After segregating the topsoil for subsequent reclamation purposes, and after blasting, the overburden (averaging 70 feet) is removed in long parallel cuts. The new exposed and blasted coal seam (averaging 25-30 feet) is removed (89 percent efficiency in terms of Btu recovered). With the exception of the first cut, overburden from each cut is placed in the previous one. Coal is loaded into trucks for transport to a coal cleaning area. Reclamation consists of grading the spoil, replacing the topsoil and initiating revegetation.

COMPONENTS	Quantity
• trucks	11
• front and loaders	2
• scrapers	8
• draglines	2
• bulldozers	12
• drilling equipment	6
• graders	2
• coal shovels	2
• cable hauler and reel	2

ENVIRONMENTAL CONCERNS

- fugitive dust and vehicular emissions
 • reclamation
 • alkaline mine drainage
 • erosion
 • noise
 • aesthetics
 • altered land use

RESOURCES USED: (Per 10^{12} Btu Produced)

RESOURCE DEPLETION

total in-place coal	59,449 tons
heat content	9,450 Btu/lb

COAL ANALYSIS

% (by weight)	
moisture	21.5
volatile matter	34.3
fixed carbon	39.6
ash	4.4
sulfur	0.4
nitrogen	1.2

ENERGY

fuel	0.8×10^9 Btu
electricity	1.1×10^6 kWh

LAND

Acres	
fixed	0.4
incremental	1.8

WATER

Acres-Foot	
consumption	1.0

COSTS

Dollars (1977)	
construction	
total construction cost	1.32×10^6
other investments and fees	0.73×10^6
operation	
general mining cost	0.28×10^6
reclamation and sediment control	2×10^6

PERSONNEL

Manhours	
construction	
non-manual, technical	1.1
non-manual, non-technical	0.2
manual	2.2
operation	
non-manual, technical	0.7
non-manual, non-technical	0.9
manual	1.9

RESIDUALS (Per 10^{12} Btu Produced)

AIR POLLUTANTS

Particulates ⁽¹⁾	GROSS (Tons)	NET (Tons)
SO ₂	0.2	0.08
NO _x	0.2	0.2
hydrocarbons	2.0	2.0
CO	0.2	0.2
	1.2	1.2

WATER POLLUTANTS

TOTAL DISSOLVED SOLIDS	GROSS (Tons)	NET (Tons)
Iron	90.9	23.9
Manganese	0.005	0.005
Aluminum	0.02	0.02
Zinc	0.006	0.006
Nickel	0.005	0.005
Total Suspended Solids	0.001	0.001
Iron	2.0	2.3
Ammonia	0.002	0.02
Sulfate	0.1	0.2
	41.1	37.7

SOLID WASTE⁽²⁾

	GROSS (Tons)	NET (Tons)
overburden removal	745	0
runoff treatment	NA	0

ENERGY PRODUCT
 raw coal = 57,910 tons

- (1) Assuming 50% reduction in fugitive dust emissions through dust suppression.
 (2) Assumes all solid waste is returned to mining pits.

SOURCES: The MINE Corporation, Annual Environmental Analysis Report, 1977.
 University of Oklahoma, Energy Alternatives: A Comparative Analysis, 1975.
 TWE, West Environmental Data Book, Volume IV, 1978.
 Hickman Associates, Inc., Environmental Impacts, Efficiency, and Cost of Energy Supply and End Use, Volume I, 1974.
 Bechtel Corporation, Energy Supply Planning Model, 1978.
 Bureau of Mines, Basic Estimated Capital Investment and Operating Costs for Coal Strip Mines, 1976.
 Energy and Environmental Analysis, Coal and Profitability, 1979.
 Bureau of Land Management, Federal Coal Management Program, Final Environmental Statement, 1979.

Underground Coal Mining - Eastern

ENERGY SYSTEM:

- SIZE** = 3 million tons per year
 • 51.4×10^{12} Btu per year equivalent
 • 20 year mine life

DESCRIPTION

- The mining involves driving main entries with production entries normal to the main entry on the right and left. As mining advances on one side of the main entry, rooms are excavated in the five foot coal seam. The strata above the seam is supported by pillars of coal. After an entire section is mined, part of the coal in the pillar is recovered (overall, about 57 percent recovery is possible) as a return to the main entry is made. With a mechanized continuous miner, many of the mining operations performed in the same section are executed simultaneously. An electric powered continuous miner either borers, digs or rips the coal from the working face. Coal is then loaded into a ratio feeder at the tail piece of a unit belt conveyor.

COMPONENTS

	Quantity
• mainline belt conveyor	1
• roof bolting machines	13
• ventilating fan	1
• continuous mining machines	11
• loading machines	11
• shuttle car	12
• ratio feeder	11
• rock duster	12
• supply motor	5
• mainline power center	5
• section rectifier	11
• auxiliary fan	13
• section belt power center	7

ENVIRONMENTAL CONCERNS

- solid waste disposal
- runoff from waste piles
- acid mine drainage
- subsidence of surface area
- noise

RESOURCES USED: (Per 10^{12} Btu Produced)

RESOURCE IMPLICATION

total on-lease coal energy content 66,264 tons
 12,850 Btu/lb

COAL ANALYSIS

	% (by weight)
moisture	3.9
volatile matter	36.1
fixed carbon	52.4
ash	9.6
sulfur	2.1
nitrogen	1.1

ENERGY

electricity 7.2×10^5 kWh

LAND

fixed 0.3 acres
 incremental 11.7

WATER

consumption 2.3 acre-feet

COSTS

	Dollars (1977)
construction	
manpower	1.7×10^5
material	1.1×10^5
equipment	3.8×10^5
other investments and fees	7.1×10^5
operation	
manpower	4.9×10^5
material	0.8×10^5
equipment	1.4×10^5
other costs	3.6×10^5

PERSONNEL

	Manhours
construction	
non-union, technical	1.3
non-union, non-technical	0.1
union	4.3
operation	
non-union, technical	3.9
non-union, non-technical	3.2
union	12.4

WASTES AND PRODUCTS: (Per 10^{12} Btu Produced)

AIR POLLUTANTS

Air emissions from equipment are not considered a problem in underground extraction since most equipment is electric powered.

particulates	negligible
SO ₂	negligible
hydrocarbons	negligible
CO	negligible
aldehydes	negligible

WATER POLLUTANTS

Total Dissolved Solids	294.4	392.0
Iron	22.4	0.02
Manganese	0.6	0.2
Aluminum	3.6	1.7
Zinc	0.1	0.02
Nickel	0.06	0.02
Strontium	0.2	0.2
Chloride	8.6	12.7
Fluoride	0.1	0.1
Calcium carbonate*	101.7	136.3
Total Suspended Solids	19.0	1.7
Iron	7.0	0.2
Ammonia	1.0	0.3
Sulfate	197.8	174.9

SOLID WASTE

from sinking the mine shaft	58.4
from treating mine water runoff	0
from extraction process	NA

ENERGY PRODUCT

raw coal - 36,910 tons

*Calcium carbonate wet emissions are greater than calcium carbonate gross emissions because calcium carbonate is added to waste water as part of the treatment process.

- SOURCES:** The MITE Corporation, *Annual Environmental Analysis Report*, 1977.
 University of Oklahoma, *Energy Alternatives: A Comparative Analysis*, 1975.
 TVA, *Basic Environmental Data Book*, Volume IV, 1978.
 Witcomb Associates, Inc., *Environmental Impacts, Efficiency, and Cost of Heavy Supply and Red Sea*, Volume 2, 1974.
 Bachtel Corporation, *Energy Supply Planning Model*, 1978.
 Bureau of Mines, *Basic Estimated Capital Investment and Operating Costs for Coal Strip Mining*, 1974.
 Bureau of Land Management, *Federal Coal Management Program, Final Environmental Statement*, 1979.

Coal Beneficiation

ENERGY SYSTEM:

- SIZE** • Process 2,437,000 tons of run-of-mine (ROM) coal each year to produce 3 million tons of clean coal
 • Hourly capacity 950 tons of ROM coal
 • Operates 3,000 hours per year, representing ten shifts per week, 230 days per year
 • 20 year plant life
 • 87.3% efficiency (in terms of Btus)
 • yield by weight is 70%

DESCRIPTION

• Coal beneficiation is a process for upgrading coal prior to its use for metallurgical or utility purposes. The purpose of beneficiation is to remove impurities (i.e., ash and/or sulfur) from raw coal. The degree of beneficiation depends on the type of coal and its ultimate use. The system described on this summary sheet (level 2 per Phillips et al.) is a relatively expensive procedure. It removes more sulfur and ash than most other types of beneficiation, and it is also more costly. The resultant cleaned coal would be used for metallurgical purposes.

COMPONENTS

- scalping screen
- crusher
- rotary breaker
- vibrator screens
- jig
- dewatering equipment
- thickeners
- filters
- concentrating tables or hydrocyclones
- flotation circuits
- thermal drying

ENVIRONMENTAL CONCERNS

- particulate emissions
- solid waste disposal
- surface water contamination from settling pond overflow and/or refuse pile runoff
- possible ground water contamination from settling pond leaching
- noise

RESOURCES USED:

(Per 10^{12} Btu Produced)

FUEL	Tons
run-of-mine (ROM) or raw coal	51,943
(assuming one ton of ROM coal has an energy content of 22 million Btus per ton)	
ENERGY (1)	
electricity	2.0×10^4 kWh
oil	5.9×10^6 Btu
LAND (2)	
washing plant	Acres
loading facility	0.2
settling pond	1.8
	2.3
WATER (3)	
consumption	Acq-Ft.
	3.7
COSTS (1976)	
construction	Dollars 4.3×10^5
operation and maintenance	3.2×10^5
PERSONNEL	
construction (1 year)	Workers
operation and maintenance	8.1
	1.5

RESIDUALS AND PRODUCTS:

(Per 10^{12} Btu Produced)

AIR POLLUTANTS	Tons (Gross)	Tons (Net) (3)
particulates	91	0.9
SO ₂	2.7	0.005
NO _x	1.8	0.6
hydrocarbons	1.1	0.2
CO	5.4	0.2
WATER POLLUTANTS		
	Tons (Gross)	Tons (Net) (3)
total dissolved solids	143	33
iron	0.2	0.007
manganese	0.2	0.03
aluminum	1.1	0.04
silica	0.06	0.005
total suspended solids	5,870	0.6
iron	4.4	0.06
manganese	0.2	0.03
sulfates	98	18
SOLID WASTE		
	Tons (Gross)	Tons (Net) (3)
primary breaking	0	0
source cleaning (5)	2	2
run-coal sizing	0	0
primary cleaning	10,157	10,157
fresh flotation	5,341	5,341
thermal drying	0	0
breaking and sizing	2	2
total	15,502	15,502
WAST		
little or none		
NOISE		
Noise may affect workers involved in cleaning coal, but there should be little or no adverse impact on receptors near beneficiation plants.		
ENERGY PRODUCTS		
cleaned coal		

- (1) These figures were calculated assuming an energy content of 12,000 Btu/lb of coal (Hittman, 1974). They are national averages (assuming an energy efficiency of 91.3%) and do not apply to elaborate (i.e., level 3) beneficiation in particular.
- (2) These coefficients may be subject to error since the data source presented only the fixed amount of land used without specifying the plant's annual output of coal. In calculating these coefficients, it was assumed here that plant output was the same as that specified in the "Notes" section of this sheet.
- (3) These figures are weighted national averages based upon regional coefficients projected by ERM for 1979. The regional coefficients were weighted in terms of Btus used. Each of the coefficients shown on this sheet is equal to total national tons of residual divided by total national Btu output. These figures include residuals from refuse piles and the beneficiation process itself. They assumed that 80% of coal preparation plants are closed cycle and that all refuse is treated. An efficiency of 90% (in Btus) was assumed.
- (4) Based on national averages in Hittman.

SOURCES: Phillips, Peter and Paul Dalziano, "Assessing the Economics of Steam Coal Preparation", Coal Mining and Processing, September, 1977.
 DOE and EPA, Engineering/Economic Analysis of Coal Preparation with SO₂ Cleanup Processes, 1978.
 Hittman Associates, Environmental Impacts, Efficiency, and Cost of Energy Supply and End Use, 1974.
 The MITES Corporation, Annual Environmental Analysis Report, 1977.
 University of Oklahoma, Energy Alternatives: A Comparative Analysis, 1975.
 Schmidt, Richard A., Coal in America, 1979.
 McGraw Hill Mining Information Service, Kentucky Coal Industry Manual, 1977.
 Bureau of Land Management, Federal Coal Management Program, Final Environmental Statement, 1979.

This page has been revised. Please refer to Appendix A, pages A-2 and A-3 for the revised information.

Conventional Boiler - Western Coal

ENERGY SYSTEM:

- SIZE** = 300 MW
 • 3,312 tons coal feed/day
 • heat rate 10,000 Btu/MWh
 • thermal efficiency 34%
 • capacity factor 55% (national average)
 • annual energy production 8.2×10^{12} Btu/year
 • 30 year life

DESCRIPTION

- Current NSPS
 - particulates $0.1 \text{ lb}/10^6$ Btu (coal input)
 - sulfur oxides $1.2 \text{ lb}/10^6$ Btu (coal input)
- Revised NSPS
 - particulates $0.03 \text{ lb}/10^6$ Btu (coal input)
 - sulfur oxides reduction varies between 70% and 90% based on sulfur content and Btu content per pound of coal.

COMPONENTS

- coal
- coal crushing/conveying system
- coal pulverizing
- p.f. boiler
- turbine
- generator
- feed water treatment
- air preheater
- economizer
- flue gas desulfurization (1)
- settling ponds
- electrostatic precipitator (ESP)
- cooling towers

ENVIRONMENTAL CONCERNS

- SO₂ emissions
- potential leachate of trace elements from ash/slag
- water use (in certain areas)
- SO₂ emissions from plants

RESOURCES USED:

(Per 10^{12} Btu Produced)

FUEL

coal: Western Rocky Mountain Province, 142,000 tons; heat content, 10,000 Btu/lb

COAL ANALYSIS

1 (by weight)

sulfur 0.6
 ash 7.7

EFFICIENCY (2)

(requirements for pollution control devices)
 electrostatic precipitator 0.89
 cooling towers 4.5

LAND

Acres/Year

plant site, permanent 12.6
 waste disposal area, temporary 5.9

WATER

Acres-Ft./Year

total 154.5

COSTS

Dollars

construction NA
 operation & maintenance NA

PERSONNEL

Workers

construction NA
 operation & maintenance 8.51

RESIDUALS AND PRODUCTS:

(Per 10^{12} Btu Produced)

AIR POLLUTANTS

	Gross	Plant Under NSPS	Plant Under Revised NSPS	Tons
particulate	9024.0	147.0	44.0	
SO ₂	1670.0	1670.0	502.0	
NO _x	1318.0	1025.0	444.0	
hydrocarbons	22.0	22.0	22.0	
CO	73.0	73.0	73.0	
arsenic	0.14	0.007	0.007	
beryllium	0.06	0.001	0.001	
cadmium	0.04	0.001	0.001	
fluorine	7.3	0.56	0.56	
lead	0.38	0.05	0.05	
mercury	0.005	0.005	0.005	
selenium	0.14	0.04	0.04	
manganese	2.5	0.14	0.14	

WATER POLLUTANTS

	Tons
BOD	1.41
COD	137.18
total suspended solids	0.53
total dissolved solids	873.53
aluminum	0.30
chromium	0.03
non-ferrous metals	110.79
zinc	0.05
sulfates	41.10
nickel	3.62
nutrients	
nitrogen	1.87
ammonia	0.06
phosphorus	0.17
surfactants	0.39

SOLID WASTE (dry weight tons)

	Without Scrubbers	With Non-Regenerative Lime Scrubbers (Revised NSPS)
scrubber sludge	0	2511.0
boiler ash	2461.1	7461.1
ESP ash	8735.1	8735.2

HEAT

stack loss 0.53×10^{12}
 cooling towers 1.41×10^{12}

ENERGY PRODUCT (3)

electricity per 10^{12} Btu output 2.93 x 10⁸ kWh

(1) Will probably only occur under NSPS.

(2) Excludes requirements for conformance with NSPS, i.e., for an FGD system.

(3) For each Btu of electricity generated, 0.53 of energy is lost out of the stack, and 1.4 Btu of energy is lost through the cooling towers.

SOURCES: U.S. Department of Energy, Materials-Process Analysis of Coal Process Technology - Final Report for Project Phase II, 1977.

The MITE Corporation, Annual Environmental Analysis Report, 1977.

U.S. Environmental Protection Agency, Development Document for Proposed Effluent Limitations Guidelines and New Source Performance Standards for the Steam Electric Power Generating Point Source, 1974.

Atmospheric Fluidized Bed Combustion - Bituminous Coal

ENERGY SYSTEM:

- SIZE:**
- 876.64 Mw gross plant output
 - 214.26 Mw net plant output
 - 2.779×10^9 Btu/hour
 - 15.4×10^{12} Btu/year at 65% capacity factor
 - power plant efficiency 35.8%
 - plant life 20 years

DESCRIPTION

- This process is based on the combustion of small pieces of coal suspended by a continuous flow of air. This suspended mass of coal is somewhat similar to a fluid in its characteristics. A limestone scrubber added directly to the combustion allows the control of SO₂ emissions. The fluidized-bed scrubber achieves SO₂ control without the use of a conventional limestone flue gas scrubber. Fluidized-beds also emit less NO_x than conventional boilers. Fluidized-bed combustion can be applied to a wide range of boiler sizes.

COMPONENTS

- main fluidized-bed boiler
- 83-85% SO₂ removal efficiency
- APC steam generator
- steam turbine system
- carbon burn-up cell
- cyclones
- fabric filter or electrostatic precipitator (ESP)
- cooling tower
- generator and transformers

ENVIRONMENTAL CONCERNS

- solid waste disposal
- particulate emissions control

RESOURCE USE:

(Per net 10¹² Btu Produced)

FUEL
 coal: bituminous, 129,506 tons
 Illinois No. 6
 energy content 10,788 Btu/lb

COAL ANALYSIS
 sulfur 3.9
 ash 9.6
 (By weight)

LAND
 min plant site 7.2 Acres⁽¹⁾
 disposal area 8.4
 total 15.6

WATER
 consumptive use 180 (1.2)
 ash 9.6

ROCKET MATERIAL
 limestone 33,285
 (3)

COSTS
 construction (5.3 years) 37,714,558
 operation & maintenance 3,418,000
 Dollars (1980)

PERFORMANCE
 approximately same value as conventional power station of equivalent capacity

RESIDUALS AND PRODUCTS:

(Per net 10¹² Btu Produced)

AIR POLLUTANTS

	Tons	PPM ⁽²⁾
particulates	138	
SO ₂	1,435	
NO _x	366	
hydrocarbons	15	
CO	56	

WATER POLLUTANTS
 same value as conventional power station of equivalent capacity

SOLID WASTE
 fly ash 42,778
 (3)

ENERGY PRODUCT
 base load electric power 2.93 x 10⁹ kWh

(1) Data values represent the life-cycle values per 10¹² Btu divided by annual energy output; i.e. 7.2 acres/10¹² Btu annually or 7.2 ÷ 20 = 0.36 acres/10¹² Btu.

(2) Generally the same as a conventional plant of equivalent capacity except that the latter uses approximately five percent of total water use for a wet sulfur dioxide scrubber.

(3) Standards for PBC have yet to be promulgated.

SOURCES: Basso, J.T., Utility Boiler Design/Cost Comparison Fluidized-Bed Combustion vs. Fine Gas Demulcerization, (EPA-600/7-77-126), 1977. Fluidized Combustion Company, Preliminary Design and Cost Estimate for an Atmospheric Fluidized-Bed Steam Converter, Tennessee Valley Authority, 1974.

Atmospheric Fluidized Bed Combustion - Western Subbituminous Coal

ENERGY SYSTEM:

- SIZE:**
- 600 Mw nominal rating
 - 568,215 Mw gross plant output
 - 535,800 Mw net plant output
 - 1.829×10^9 Btu per hour
 - 151 (on strip operation)
 - 15.82×10^{12} Btu/year
 - net plant efficiency of 34.42%
 - plant life 20 years

DESCRIPTION

This process is based on the combustion of small pieces of coal suspended by a continuous flow of air. This suspended mass of coal is somewhat similar to a fluid in its characteristics. A limestone sorbent added directly to the combustion allows the control of SO_2 emissions. The fluidized-bed therefore achieves SO_2 control without the use of a conventional limestone flue gas scrubber. Fluidized-beds also emit less NO_x than conventional boilers. Fluidized-bed combustion can be applied to a wide range of coals and boiler sizes.

COMPONENTS

- main fluidized-bed boiler
- AFRC steam generator
- steam turbine system
- carbon burn-up cell
- cyclones
- fabric filter, more than 98% efficient
- cooling tower
- generator and transformers

ENVIRONMENTAL CONCERNS

- solid waste disposal
- particulate emissions control

RESOURCES USED:

(Per Net 10^{12} Btu Produced)

FUEL
Coal: Western subbituminous,
Powder River, Wyoming,
HRV 8053 Btu/lb

COAL ULTIMATE ANALYSIS

	% (by weight)
carbon	47.0
hydrogen	6.5
nitrogen	0.7
oxygen	37.1
sulfur	0.9
ash	7.8

LAND
(1)
Acres
total land use
29.1
site only
20.4

WATER
consumptive use
 10^6 Gallons
190(17)

SOLVENT MATERIAL
limestone
Tons
12,829

COSTS
Dollars (Mid 1977)
construction
18,300,000(17)
operation & maintenance
356,110

PERSONNEL

approximately same value as
conventional power station
of equivalent capacity

RESIDUALS AND PRODUCTS:

(Per Net 10^{12} Btu Produced)

AIR POLLUTANTS
Tons
particulates
1,737(2)
 SO_2
582
 NO_x
less than
hydrocarbons
conventional
CO
power station
of equivalent
capacity at
85% removal

WATER POLLUTANTS
approximately same values
as conventional power
station of equivalent
capacity

SOLID WASTE
dry weight
Tons
25,296

ENERGY PRODUCT
base load electric power
kWh
 2.93×10^8

- (1) Data values represent life-cycle values per 10^{12} Btu divided by annual energy output; i.e. 29.1 acres/ 10^{12} Btu annually or $29.1 \div 20 = 1.46$ acres/ 10^{12} Btu.
- (2) Operating at 85% efficiency of sulfur removal. At 85% efficiency, the SO_2 emission would be 483 tons/ 10^{12} Btu. This plant is designed to meet a SO_2 emission standard of 1.2 lbs SO_2 /MWh Btu.
- (3) Generally, the same as conventional power plant of equivalent capacity except that the latter uses approximately three percent of total water use for a wet sulfur oxide scrubber.
- (4) Standards for FBC have yet to be promulgated.

SOURCES: Bradley, W.J. et al., Conceptual Design of an Atmospheric Fluidized-Bed (AFBC) Electric Power Generating Plant-Interim Report, U.S. Department of Energy, 1978.
Stons and Webster Engineering Corporation, Technical Notes for the Conceptual Design for an Atmospheric Fluidized-Bed Direct Combustion Power Generating Plant, U.S. Department of Energy, 1978.

Magnetohydrodynamic System

ENERGY SYSTEM:

- SIZE = 1,993 MWe gross output
- = 1,932 MWe net output
- = plant efficiency 49.8%
- = load factor 63%
- = 37.5×10^{12} Btu net output per year

DESCRIPTION

- Generation of base load electric power using magnetohydrodynamics. Seed material (Pecanium) is mixed with a finely ground coal and ionized at a high temperature and passed through a magnetic field to generate electricity.

COMPONENTS

- pulverized coal burner (2 stage combustors)
- MHD generators
- seed recovery system
- steam bottoming cycle

ENVIRONMENTAL CONCERNS

- particulate emissions
- potential for NO_x emissions

NA = Not Available from cited source.

RESOURCES USED: (Per 10^{12} Btu Produced)

FUEL
coal: Illinois No. 6
(bituminous)

LAND
total (1)

WATER

consumptive

COSTS

construction (2)
operation & maintenance (3)

PERSONNEL

construction
operation & maintenance

Tons
95,890

Acres
47.3

Acres-Foot
300

Dollars (1975)

\$7,000,000
1,000,000

Man-hours
NA

NA

RESIDUALS AND PRODUCTS: (Per 10^{12} Btu Produced)

AIR POLLUTANTS

particulates
 SO_2
 NO_x

WATER POLLUTANTS

blowdown from cooling and steam system. Similar to emission from an electric power station.

SOLID WASTE

furnace wastes
fly ash

ENERGY PRODUCT

electrical energy

OTHER PRODUCT

sulfur

Tons

30
500
300

Tons

7,600
1,340

kWh

2.93×10^6

Tons

5,100

- (1) Represents total land required for the plant, divided by annual energy output, measured in trillion Btu.
(2) Represents construction costs, divided by annual energy output, measured in trillion Btu.
(3) Includes fuel cost but excludes recovery of capital.

SOURCE: General Electric Company, Study of Advanced Energy Conversion Techniques for Utility Applications Using Coal or Coal-Derived Fuel, 1976.

Coal-Oil Mixture Retrofit Boiler

ENERGY SYSTEM:

SIZE • 300 MW

- 55% capacity factor
- 35% thermal efficiency
- 9800 Btu/kWhr heat rate
- 5 x 10¹² Btu/yr net energy output
- Operates 20 hr. per day, 312 days per year
- No. 6 fuel oil
- Appalachian Bituminous coal

DESCRIPTION (a)

- Recently constructed oil-designed boilers are a favorable target for coal-oil mixture (COM) conversion. These units generally require certain modifications. Use of wear-resistant alloys and enlarging orifices are necessary to prevent deterioration and to ensure a compatible viscosity range. Existing fuel train pumps may have to be replaced with wear-resistant rotary gears or progressive cavity-type pumps; valves will also need to be replaced with full-bore, ball-type units for control. Additional southblower capacity may be required to control the buildup of residue. Additional particulate and sulfur oxide controls will be needed to control emissions. The capacity of the bottom ash removal system may need augmentation. Assuming that the COM is purchased from a central COM preparation plant, the existing oil unloading facility can be used to unload COM. However, an independent COM storage and handling system will be needed to achieve dual fuel capacity (so that oil can be burned periodically to minimize the effect of derating).

MAJOR EQUIPMENT COMPONENTS

- COM pumping system
- Electrostatic precipitator (ESP)
- Southblower
- Bottom ash hopper and handling system
- Flue gas desulfurization (FGD)

ENVIRONMENTAL CONCERNS (b)

- Air pollution (sulfur oxides, nitrogen oxides, particulates, carbon monoxide, hydrocarbons, and hazardous trace substances)
- Ash disposal
- Leachates
- Spills/Leaks

RESOURCES USED:

(Per 10¹² Btu Output)

FUEL

50% coal-oil mix by weight
4.8 x 10⁵ barrels
Cost - \$6.57 x 10⁶(c)

FUEL ANALYSIS

Heating Value - 15,930 Btu/lb
Density - 8.82 lb/gal
Sulfur - 1.5%
Ash - 3%

ENERGY

Fuel train
FGD (limestone wet scrubber)
ESP
NO_x control
SO₂ control and ash handling

LAND

Waste disposal (landfill)

WATER

Consumption

COST

Retrofit (c)
Annual operating & maintenance (a)

PERSONNEL

Construction (retrofit)
Operating and maintenance (total) (f)
nonmanual, technical
nonmanual, nontechnical
manual

RESIDUALS AND PRODUCT:

(Per 10¹² Btu Output)

AIR POLLUTANTS (tons) (a)

	Gross	MSPS Net
Particulates	1965	144
Sulfur oxides	2527	1297
Nitrogen oxides	961	648
Carbon monoxide	38	40
Hydrocarbons	17	18

WATER POLLUTANTS

	Gross	Net
SOLID WASTE (tons) (b)		
Spent sorbent and sodium bicarbonate	NA	NA
Ash	NA	NA
Total	NA	NA

ENERGY PRODUCT

Electricity 2.93 x 10⁸

* Assume O/M manpower levels are similar to that used by a similarly sized oil-fired power plant.

SOURCES:

- Pruce, Leslie M., 1980. COMs: Boiler Fuel of the Future? *POWER*, Vol. No. 2, p. 110.
- Brown, Richard (editor), 1979. Health and Environmental Effects of Coal Technologies. Prepared for Federal Interagency Committee on Health and Environmental Effects of Energy Technologies, Report No. DOE/REN/EPA-04.
- George, Thomas J., T.C. Campbell, and Perry D. Bergmann, 1979. Coal-Oil Mixtures: A Good Idea from DOE. Coal Mining and Processing, Vol. 16, No. 3, p. 71.
- DOE/EPA, 1977. Energy Consumption of Environmental Controls: Fossil Fuel, Steam Electric Generating Industry.
- Foo, O.K., et al., 1980. Market Assessment and Financial Analysis of COM Conversion. The MITRE Corporation (to be published).
- Bechtel Corporation, 1978. Energy Supply and Planning Model. San Francisco, California.
- U.S. Environmental Protection Agency, 1975. Compilation of Air Pollutant Emission Factors. EPA Publication No. AP/42.

Central Coal-Oil Mixture Preparation Plant

ENERGY SYSTEM:

- SIZE** (a)
- 33 million barrels (6.24×10^8 ton) per year of a 50/50 mixture of coal-oil
 - 194.7 $\pm 10^3$ Btu per year
 - Operates 10 hours per day
 - 311 days per year
 - 10 year plant life
 - No. 6 fuel oil
 - Appalachian bituminous coal

DESCRIPTION

- (a) When a large central preparation/distribution COM facility is built, it is most likely to also include an elaborate coal beneficiation capability. Generally, beneficiated coal would be delivered by a unit train to a rotary car dump and then moved to a transfer house. From the transfer house, the coal is either brought to a live or dead storage stockpile through a stacker/reclaimer or it is introduced to the coal-oil mixture or the coal beneficiation circuit through a 24-hour capacity surge surge silo. Coal in the COM circuit is first passed through hoppers which have a 4-hour holdup. From the hoppers, the coal is moved through a pulverizer (e.g., a vertical roll mill) which reduces the coal to 90 percent through 200 mesh. Cyclone separator feeders then transmit the coal for mixing with oil. Either continuous or batch mixing may be employed. (Batch mixing appears the most likely for the initial facilities.) Batch mixing consists of filling a tank to a specified level with oil and then blending in coal until a second level is reached which represents the desired mixture. It is assumed that the COM is delivered to market through existing No. 6 fuel oil distribution systems.

MAJOR COMPONENTS

(1), (a)	No. of Units
Rotary Car Dump	1
Stacker/Reclaimer	1
Coal Stockpile	2
Process Surge Silo/Hopper	1
Pulverizer	1
Mixing Tank	3
Oil/COM Storage Tank (100,000 bbl)	25

ENVIRONMENTAL CONCERNS

- (a) Evaporative losses from oil storage and transfer operations
- Fugitive dust
 - Rumoff
 - Noise
 - Leaks/Spills

RESOURCES USED:

(Per 10^{12} Btu Produced)

- FUEL** (a)
- Coal: Generally beneficiated Appalachian bituminous
 - Operating Amount - 1.6×10^4 t (2)
 - Oil: No. 6 Fuel Oil
 - Operating Amount - 9.4×10^4 barrels

FUEL ANALYSIS

- (a)
- Coal: Level C beneficiated
 - Heating Value - 13,060 Btu/lb
 - 22 sulfur maximum
 - \$27/ton (3)

OIL

- Heating Value - 18,800 Btu/lb
- 12 sulfur
- \$18.00/barrel (3)
- Density - 8.1 lb/gal

OPERATING ENERGY

- Electricity: 4.7×10^5 kWh

LAND

- Fixed Land (a): 1.34 acres

WATER

- Consumptive use: Negligible

COSTS

- (a), (c) 1978 Dollars
- Total investment requirements: 6.40×10^6
 - total plant cost, insurance, taxes, interest, and working capital: 4.16×10^6
 - Total operating cost: 9.00×10^5
 - raw materials and utilities: 1.42×10^5
 - direct labor: 0.42×10^5
 - plant maintenance (materials and manpower): 1.85×10^5
 - overhead: 2.12×10^5
 - taxes, insurance, and depreciation: 3.19×10^5

PERSONNEL

- Construction total (c): 1.54
- normal, technical: 0.28
- normal, non-technical (3): 0.04
- normal (3): 1.22
- Operation, Maintenance and Supervision: 0.64

RESIDUALS AND PRODUCTS:

(Per 10^{12} Btu Produced)

AIR POLLUTANTS

- Fugitive dust: M (6)
- Hydrocarbons: M (6)

WATER POLLUTANTS

- NA

SOLID WASTE

- Negligible

ENERGY PRODUCTS

- 50% oil - 50% coal (by weight)
- Heating value - 15,920 Btu/lb
- Density - 370.4 lb/barrel
- Cost - \$1.67 $\pm 10^3$ @ 12"10 BCF with 60% equity and 25% interest on debt
- Amount - 3.15×10^5 Tons

(1) The COM facility is assessed without a coal beneficiation circuit.

(2) Assume a coal throughput of 10,000 T/day.

(3) Costs are based on DOE Monthly Energy Review January 1980.

(4) Assume that land required for the COM facility would be about that needed for a similarly sized petroleum bulk station and minimal (11.5 acres for 60,000 T) coal storage needs.

(5) Assume construction manpower needs would be about that needed for a similarly sized petroleum bulk station.

(6) Fugitive dust and evaporative losses are highly dependent on site specific events and operating modes. For example, factors affecting the rate of hydrocarbon emissions include: true vapor pressure of the liquid stored, temperature changes in the tanks, height of the vapor space, tank diameter, schedule of tank filling and emptying, mechanical condition of tank and seals, and type of tank and type of paint applied to outer surfaces.

SOURCES: (a) George, T. J. (1978). "A Commercial Coal-oil Preparation Facility: Concepts and Economics Assuming a 50 Percent Mixture (33 Million Barrels per year)." U.S. Department of Energy, Morgantown, WV. Process Evaluation Office, Report No. PE/MS-78/2.

(b) Brown, R. (ed.) (1979). "Health and Environmental Effects of Coal Technologies. Prepared by The NITEL Corporation for the Federal Interagency Center on Health and Environmental Effects of Energy Technologies. NITEL Report No. NTE-7900015901.

(c) Bechtel Corporation (1978). Energy Supply and Planning Model. San Francisco, California.

Eastern Coal Unit Train

ENERGY SYSTEM:

- NOTE**
- one unit train carries 10,500 tons of coal per trip
 - unit train consists of 105 freight cars each carrying 100 tons of coal
 - four diesel locomotives of 3,000 HP each
 - ten square freight cars are reserved for each unit train
 - each unit train is assumed to make 50 round trips per year. Each trip is 700 miles (1126 mi) one way
 - 99.75% of the coal loaded on a unit train is successfully delivered to its destination—0.25% inefficiency accounts for losses in handling and wind losses in transportation
 - 30 year lifetime of cars

NEW-CHIPPINGS

- unit train consists of equipment dedicated to transportation of coal from a single origin to a single destination. The unit train described in this summary runs on diesel fuel (99% of all rail ton-miles in the U.S. are by diesel); 33 are on electrically-powered tracks)

CONSUMPTION

- freight cars
- locomotives
- engineers

ENVIRONMENTAL CONCERNS

- air pollution
- railroad crossing hazards
- noise

RESOURCES USED: (Per 10¹² Btu Produced)

FUEL

coal transported

30,811 tons
12,850 Btu/lb

ENERGY

diesel

0.55 x 10¹⁰

LAND⁽¹⁾

MATERIALS⁽²⁾

aluminum
brass & bronze (castings)
chromium
copper
iron
manganese
nickel
steel

tons
1.87
0.75
0.10
2.58
NA
1.33
0.02
185

COSTS

construction (r)(3)(4)
electrical equipment
miscellaneous equipment
other construction expenses
total
operation and maintenance⁽⁵⁾
auxiliary energy (diesel)
other
total

Dollars (1978)
50,000
274,000
9,000
334,000
39,000
238,000
297,000

PERSONNEL

construction (1 year)
operation & maintenance

NA
5.16

RESIDUALS AND PRODUCTS: (Per 10¹² Btu Transported)

AIR POLLUTANTS⁽⁶⁾

particulates⁽⁷⁾
SO₂
NO_x
hydrocarbons
CO
aldehydes, etc.

tons
102.9
3.7
3.2
2.5
3.4
0.6

NOISE

Noise inside diesel locomotives ranges at least as high as 112 decibels (dBA). 100 feet from a moving train, noise may be approximately 95 dBA, while at 1000 feet the noise level may be about 75 dBA. Locomotive whistle noise at 1000 feet from a train has been recorded at 85 dBA, dropping below 70 dBA at 1300 feet. The amount of noise generated is affected by train speed, the number of cars in a train, track condition and topography. Muffling of tracks help reduce noise, and noise barriers can obstruct or dissipate sound emissions. Federal design noise levels range from 55 dBA (maximum desirable for residences) to 75 dBA.

ENERGY PRODUCT

transported coal

tons
38,711

- (1) Land use value has been excluded, as it cannot be exclusively associated with coal transportation.
(2) These figures do not include materials (construction costs) for tracks, loading facilities and unloading facilities.
(3) This represents the costs of construction, divided by the annual volume transported.
(4) Total construction costs shown here do not include labor.
(5) O&M costs include tracks, but exclude loading facilities and unloading facilities.
(6) Annual efficiency 8 percent.
(7) Includes particulates from locomotives and fugitive emissions.

SOURCES: Western Association, Environmental Reports, Efficiency and Cost of Energy Supply and End Use, Volume 7, 1974.
Federal Corporation, Energy and Supply Planning Model, 1978.
International Research & Technology Corporation, TECHN, 1978.
University of Oklahoma, Energy Alternatives: A Comparative Analysis, 1975.
C. Burris, E. Handbook of Noise Control, 1977.
FEDCO, Inc., Environmental Assessment of Coal Transportation, 1978.

Western Coal Unit Train

ENERGY SYSTEM:

- SIZE**
- One unit train carries 10,000 tons of coal per trip
 - Unit train consists of 100 freight cars each carrying 100 tons of coal.
 - Four diesel locomotives of 3,000 HP each
 - Five spare freight cars are reserved for each unit train.
 - Each unit train is assumed to make 90 round trips per year. Each trip is 700 miles (1120km) one way.
 - 95.7% of the coal loaded on a unit train is successfully delivered to its destination--0.2% inefficiency accounts for losses in handling and wind losses in transportation.
 - 30 year lifetime of cars

DESCRIPTION

- Unit trains consist of equipment dedicated to transportation of coal from a single origin to a single destination. The unit train described in this summary runs on diesel fuel (95% of all rail ton-miles in the U.S. are by diesel); 1% are on electrically-powered trains).

COMPOSITION

- freight cars
- locomotives
- caboose

ENVIRONMENTAL CONCERNS

- air pollution (particulates)
- railroad crossing hazard
- noise

RESOURCES USED:

(Per 10¹² Btu Transported)

PRODUCT	
coal transported	33,040 tons
energy content	9,450 Btu/lb
ENERGY	
diesel	1.30 x 10 ¹⁰
LOSS (%)	
	NA
MATERIALS (%)	
aluminum	2.34
brass & bronze (coatings)	1.02
chromium	0.13
copper	3.31
iron	NA
manganese	1.80
nickel	0.03
steel	251.33

COSTS

	Dollars (1976)
construction	
electrical equipment	66,000
miscellaneous equipment	372,000
other construction expenses	13,000
total	451,000
operation and maintenance (1)	
auxiliary energy (2) (diesel)	33,000
other	320,000
total	403,000

PERFORMANCE

	Hours
construction (1 year)	NA
operation & maintenance	7.02

RESIDUALS AND PRODUCTS:

(Per 10¹² Btu Transported)

AIR POLLUTANTS (%)	tons
particulates	119.377
SO ₂	5.0
NO _x	4.4
hydrocarbons	3.0
CO	4.4
aldehydes, etc.	0.8

NOISE

Noise inside diesel locomotives ranges at least as high as 112 decibels (dBA). 100 feet from a moving train, noise may be approximately 95 dBA, while at 1000 feet the noise level may be about 75 dBA. Locomotive whistle noise at 1000 feet from a train has been recorded at 85 dBA, dropping below 70 dBA at 1300 feet. The amount of noise generated is affected by train speed, the number of cars in a train, track condition and topography. Bidding of tracks help reduce noise, and noise barriers can obstruct or dissipate sound emissions. Federal design noise levels range from 55 dBA (maximum desirable for residences) to 75 dBA.

ENERGY PRODUCT

	tons
transported coal	33,040

- Land use value has been excluded as it cannot be cumulatively associated with coal transportation.
- These figures do not include materials (construction costs) for tracks, loading facilities and unloading facilities.
- This represents the costs of construction, divided by the gross volume transported.
- Total construction costs shown here do not include labor.
- NA eqts include tracks, but exclude loading facilities and unloading facilities.
- Uncontrolled.
- Includes particulates from locomotives and fugitive emissions.

SOURCES: Hixson Associates, *Environmental Impacts, Efficiency, and Cost of Energy Supply and End Use*, Volume 1, 1974.
 Bechtel Corporation, *Energy Supply Planning Model*, 1978.
 International Research & Technology Corporation, *TECHNET*, 1978.
 University of Oklahoma, *Energy Alternatives: A Comparative Analysis*, 1975.
 C. Harris, M., *Handbook of Noise Control*, 1971.
 PEDCO, Inc., *Environmental Assessment of Coal Transportation*, 1978.

Eastern Coal Conventional Train

ENERGY SYSTEM:

- SIZE** • One conventional train carries 1 ton of coal per trip.
- A conventional train is assumed to consist of 93 freight cars, each of which carries 45 tons of freight. 17 of these freight cars carry coal. The other 48 cars carry non-coal products.
- Each conventional train is assumed to make 10 round trips per year. Each trip is 500 miles (483 mi) one-way.
- 99.73% of the coal loaded on a conventional train is successfully delivered to its destination—0.23% inefficiency accounts for losses in handling and wind losses in transportation.
- 30 year lifetime of cars

DESCRIPTION

- Conventional trains transport several commodities simultaneously. Only one of these products is coal. The conventional train described in this summary runs on diesel fuel (75% of all rail ton-miles in the U.S. are by diesel; 15 are by electrically-powered trains).

COMPOSITION

- freight cars containing coal
- freight cars containing other products (all coefficients shown on this summary sheet are pre-ented to include freight cars containing non-coal products)

ENVIRONMENTAL CONCERNS:

- air pollution (particulates)
- noise pollution, particularly in populated areas
- railroad crossing hazards

RESOURCES USED:

(Per 10⁶ Btu Transported)

FUEL

coal transported 39,000 tons

energy content 12,450 Btu/lb

ENERGY

diesel (1)

2.08 x 10¹⁰

LAND

NA

MATERIALS (2)

aluminum 5.64 tons

brass & bronze 3.13

chromium 0.40

copper 9.76

iron NA

manganese 6.02

nickel 6.09

steel 844

TOOLS

construction (2) (3) (4) Dollars (1978)

electrical equipment 138,000

miscellaneous equipment 1,136,000

other construction expenses 36,000

total 1,310,000

operation and maintenance (5)

auxiliary energy (diesel) 31,000

other 824,000

total 855,000

PERSONNEL

construction NA

operation & maintenance 3.91

RESIDUALS & PRODUCTS:

(Per 10⁶ Btu Transported)

AIR POLLUTANTS (6)

	Tons (7)
particulates	101.7
SO ₂	2.6
NO _x	2.9
hydrocarbons	2.0
CO	2.7
aldehydes, etc.	0.3

NOISE

Noise inside diesel locomotives ranges at least as high as 112 decibels (dBA). 100 feet from a moving train, noise may be approximately 95 dBA, while at 1000 feet the noise level may be about 75 dBA. Locomotive whistle noises at 1000 feet from a train has been recorded at 85 dBA, dropping below 70 dBA at 1,300 feet.

The amount of noise generated is affected by train speed, the number of cars in a train, track condition, and topography. Widening of tracks helps reduce noise, and man-made barriers can obstruct or dissipate sound emissions. Federal design noise levels range from 55 dBA (maximum desirable for residences) to 75 dBA (open land).

ENERGY PRODUCT

	Tons
transported coal	38,911

- (1) Land use value has been excluded as it cannot be exclusively associated with coal transportation.
- (2) These figures do not include materials (construction costs) for tracks, loading facilities and unloading facilities.
- (3) This represents the costs of construction, divided by the total volume transported.
- (4) Total construction costs shown here do not include labor.
- (5) O&M costs include tracks, but exclude loading facilities, and unloading facilities.
- (6) Uncontrolled.
- (7) Includes particulates from locomotives and fugitive emissions.

SOURCES: Babcock Corporation, Energy Supply Planning Model, Volume I, 1975, and variations, 1978.

Birkmeyer Associates, Environmental Impacts, Efficiency, and Cost of Heavy Supply and Red Sea, Volume I, 1974.

International Research & Technology Corporation, TECHNOL, 1976.

University of Delaware, Energy Alternatives: A Comparative Analysis, 1975.

Orrill Harris, ed., Handbook of Noise Control, 1956.

EDCO, Inc., Environmental Assessment of Coal Transportation, 1978.

Western Coal Conventional Train

ENERGY SYSTEM:

- SIZE**
- One conventional train carries 1,445 tons of coal per trip.
 - A conventional train is assumed to consist of 85 freight cars, each of which carries 85 tons of freight. 17 of these freight cars carry coal. The other 68 cars carry non-coal products.
 - Each conventional train is assumed to make 20 round trips per year. Each trip is 300 miles (483 km) one way.
 - 30 year lifetime of cars
 - 99.73% efficiency; 0.23% losses are due to loading, unloading, and windage during transit.

DESCRIPTION

- Conventional train transport several commodities simultaneously. Only one of these products is coal. The conventional train described in this summary runs on diesel fuel (92% of all rail ton-miles in the U.S. are by diesel); it are by electrically-powered trains).

COMPONENTS

- freight cars containing coal
- freight cars containing other products (all coefficients shown in this summary sheet are provided to exclude freight cars containing non-coal products)
- locomotives
- caboose
- tracks
- loading and unloading facilities
- yard facilities, including switch-
yard buildings

ENVIRONMENTAL CONCERNS

- air pollution (particulates)
- noise pollution, particularly in populated areas
- railroad crossing hazards

RESOURCES USED: (Per 10¹² Btu Transported)

PRODUCT	
coal transported	33,040 tons
energy content	9,450 Btu/lb

ENERGY	Btus
diesel	1.47 x 10 ¹⁰

LAND (1)	HA

MATERIALS (2)	Tons
aluminum	7.57
brass & bronze	4.52
chromium	0.54
copper	13.27
iron	NA
nickel	6.18
steel	0.12
	11.47

COSTS	Dollars (1978)
construction(1)(3)(4)	188,000
electrical equipment	1,348,000
miscellaneous equipment	52,000
other construction expenses	1,785,000
total	
operation & maintenance(5)	43,000
auxiliary energy (diesel)	1,481,000
other	1,500,000
total	

PERSONNEL	Workers
construction	NA
operation & maintenance	5.32

RESIDUALS & PRODUCTS: (Per 10¹² Btu Transported)

AIR POLLUTANTS (6)	Tons
particulates	138.4(7)
SO ₂	3.5
NO _x	4.0
hydrocarbons	2.7
CO	3.7
aldehydes, etc.	0.6

NOISE

Noise inside diesel locomotive ranges at least as high as 112 decibels (dBA). 100 feet from a moving train, noise may be approximately 95 dBA, while at 1000 feet the noise level may be about 75 dBA. Locomotive whistle noise at 1000 feet from a train has been recorded at 85 dBA, dropping below 70 dBA at 1300 feet.

The amount of noise generated is affected by train speed, the number of cars in a train, track condition and topography. Widening of tracks helps reduce noise, and sound barriers can obstruct or dissipate sound emissions. Federal design noise levels range from 55 dBA (rural areas desirable for residences) to 75 dBA (open land).

ENERGY PRODUCT	Tons
transported coal	32,910

- (1) Land use value has been excluded as it cannot be exclusively associated with coal transportation.
 (2) These figures do not include materials (construction costs) for tracks, loading facilities and unloading facilities.
 (3) This represents costs of construction, divided by the annual volume transported.
 (4) Total construction costs shown here do not include labor.
 (5) O&M costs include tracks, but exclude loading facilities, and unloading facilities.
 (6) Uncontrolled.
 (7) Includes particulates from locomotives and fugitive emissions.

SOURCES: Bechtel Corporation, Energy Supply Planning Model, Volume I, 1975, and revisions, 1978.
 Bituminous Associates, Environmental Impacts, Efficiency, and Cost of Energy Supply and End Use, Volume I, 1974.
 International Research & Technology Corporation, TCRES, 1978.
 University of Oklahoma, Energy Alternatives: A Comparative Analysis, 1975.
 Cyril Harris, ed., Handbook of Noise Control, 1957.
 FERC, Inc., Environmental Assessment of Coal Transportation, 1978.

Barge Transportation - Eastern Coal

ENERGY SYSTEM:

SIZE • A barge tow consists of fifteen barges, each with a capacity of 1,400 tons of coal. The barge tow is propelled by a single diesel-powered 4500 horsepower tugboat.

DESCRIPTION

- Expected lifetime of barges is 30 years.
- Average speed is estimated to be 9 mph (14.4 kph), average haul distance is estimated to be 170 miles (one way), and an estimated 116 round trips are made annually. Approximately 1 week per year are reserved for maintenance and miscellaneous delays.
- Annual throughput of eastern coal (12850 Btu/lb) is approximately 62.6×10^{12} Btu.
- TSP losses negligible due to low transit speeds and small exposure area of coal-piles on barge.

COMMENTS

- 15 steel barges, each with 1400 ton capacity
- 1 - 4,500 horsepower diesel-powered tugboat
- loading and unloading facilities
- commercial navigation facilities (channels, aids to navigation, locks, dams, etc.)

MAJOR ENVIRONMENTAL PROBLEMS

- Waterway traffic congestion
- Shoreline erosion due to tugboat wakes
- Potential water quality degradation from diesel fuel and coal spillage

RESOURCES USED:

(Per 10^{12} Btu of Annual Throughput)

FUEL	
Coal	38912 tons
Energy content	12850 Btu/lb
ENERGY	
Diesel fuel	4.59×10^9 Btu consumed per 10^{12} Btu moved

MATERIALS

	Tons
Carbon steel	60.2
Alloy steel	0.7
Stainless steel	0.1
Total Steel	61.0
Copper	0.5
Aluminum	0.6
Manganese	0.5
Chromium	0.1
Cast Iron	1.7

COSTS

	1978 Dollars ($\times 10^6$)
Capital	
Construction Costs	0.1
Operating Costs (excludes fuel)	
Labor	0.011
Materials	0.011
Taxes	0.003
Total	0.025

PERSONNEL

	Manhours/yr
Construction (man years)	N/A
Operation and Maintenance	0.5

RESIDUALS AND PRODUCTS:

(Per 10^{12} Btu Annual Throughput)

AIR POLLUTANTS	Tons
Particulates(a)	0.35
SO _x	0.55
NO _x	7.71
Hydrocarbons	0.62
CO	1.68

ENERGY PRODUCT

	Tons
Transported coal	38913

(a) Particulates from diesel fuel combustion. Windage losses of coal dust are estimated to be negligible.

SOURCES: Bechtel Corporation, "Energy Supply Planning Model," Vol. 1, 1975, and revisions, 1978.

NECO, Inc., "Environmental Assessment of Coal Transportation," 1978.

U.S. Environmental Protection Agency, "Compilation of Air Pollutant Emission Factors, 3rd Edition," AP-42, 1978.

Barge Transportation - Western Coal

ENERGY SYSTEM:

SIZE • A barge tow consists of 15 barges, each with a capacity of 1,400 tons. Total capacity of each tow is 21,000 tons of coal per trip. The 15 barges are propelled by a single 4,200 horsepower diesel-fueled tugboat.

DESCRIPTION

- Expected lifetime of barges is 30 years.
- Assuming an average speed of 9 mph (14.4 kph), average haul distance of 400 miles (640 km) one way, average load/unload time (total) of 10 hours, one day layover per trip, and 21 days scheduled maintenance per year results in a total of 67.2 trips per year.
- Energy transported is equal to 26.7×10^{12} Btu/year.
- TSP losses (windage) are estimated to be negligible due to low speeds, small exposed surface areas and high moisture content of western coal.

COMPONENTS

- 15 steel barges, each with 1400 ton capacity
- 1 - 4,200 horsepower diesel powered tugboat
- loading and unloading facilities
- commercial navigation facilities (channels, aids to navigation, locks, dams, etc.)

MAJOR ENVIRONMENTAL PROBLEMS

- Waterway traffic congestion
- Shoreline erosion due to tugboat wash
- Potential water quality degradation from spillage of diesel fuel and/or coal

(a) Particulates are from diesel fuel combustion. Windage losses estimated to be negligible.

SOURCES: Bechtel Corporation, "Energy Supply Planning Model," Vol. 1, 1973, and revisions, 1978.

PERCO, Inc., "Environmental Assessment of Coal Transportation," 1978.

U.S. Environmental Protection Agency, "Compilation of Air Pollutant Emission Factors, 3rd Edition," AP-42, 1978.

RESOURCES USED:

(Per 10^{12} Btu throughput)

ENERGY TRANSPORTED

Coal 32,011 tons
Energy content 9450 Btu/lb

FUEL

Diesel fuel 1.30×10^{10} Btu consumed per 10^{12} Btu of coal transported

MATERIAL

Carbon steel 141.3
Alloy steel 1.4
Stainless steel 0.3
Total steel 143.0

Copper 1.1
Aluminum 1.3
Manganese 1.1
Chromium 0.1
Cast iron 3.9

COSTS

Capital Costs 1978 Dollars $\times 10^6$
Construction cost 0.200
Operating Costs (excluding fuel)
Labor 0.026
Materials 0.023
Losses 9.307
Total 0.056

PERSONNEL

Construction (man years) N/A
Operation & Maintenance 1.20

RESIDUALS AND PRODUCTS:

(Per 10^{12} Btu of annual throughput)

AIR POLLUTANTS

Particulates(a)	Tons
SO _x	1.57
NO _x	1.47
Hydrocarbon	22.03
CO	1.76
	4.79

ENERGY PRODUCT

Transported coal 32,011 tons

NOTE: THIS PRESENTATION IS BASED UPON ESTIMATES OF HOW BARGE TRANSPORTATION COULD DEVELOP IN THE WEST.

Coal Transportation by Truck - Eastern Coal

ENERGY SYSTEM:

- SIZE**
- One over-the-road tractor trailer has a net carrying capacity of 25 tons per trip. Due to the economics of coal transportation by truck, the economically feasible maximum one way distance per trip is limited to 100 miles.
 - Each truck is assumed to operate 240 days per year, 10 hours per day and have an average speed of 20 miles per hour, with a round trip distance of 60 miles. Accordingly, each coal truck makes a projected 500 round trips per year and results in a total of 1.2×10^6 net ton miles annually.
 - Expected life of each truck is seven years.
 - Annual energy throughput estimated to be 0.51×10^{12} Btu.

DESCRIPTION

- Over the road transportation of coal represents a small segment of the coal transportation sector. Due to distance constraints, minimal truck transport of coal is anticipated in western coal supply regions.

COMPONENTS

- 25 ton tractor-trailer trucks
- Loading and unloading facilities

MAJOR ENVIRONMENTAL PROBLEMS

- Air emissions from diesel fuel combustion
- Noise
- Increased traffic levels on secondary roads
- Road damage caused by overweight trucks
- Fugitive dust emissions (coal dust)

RESOURCES USED:

(Per 10^{12} Btu of Energy Delivered Annually)

FUEL	
Coal	38,946 tons
Energy Content	12,850 Btu/lb
ENERGY	
Diesel Fuel ^a	3.13×10^9 Btu

MATERIALS	
Carbon steel	22.6
Cast iron	0.6
Structural steel	3.8
Steel plate "1.5" thick	3.2

COSTS	
Construction	0.15
Operation and maintenance (including fuel)	0.19
	(1978 Dollars $\times 10^6$)

PERSONNEL

Construction	N/A
Operation and maintenance	4.9

RESIDUALS AND PRODUCTS:

(Per 10^{12} Btu Transported Annually)

AIR POLLUTANTS	
TSP	35.16 ^b
SO _x	0.29 ^c
NO _x	1.87
CO	2.95
HC	0.47
Aldehydes	0.03
Organic Acids	0.03

NOISE

The major sources of noise from trucks are from the engine, exhaust, and tires. Mufflers can reduce exhaust noise from 100 dba to 90 dba.

ENERGY PRODUCT

Transported coal	38911 tons
------------------	------------

^aBased upon a 3.3 mpg (loaded), 5 mpg (unloaded) composite average. FIDCo (1978). This is equivalent to 22,700 gallons per 10^{12} Btu of annual throughput.

^bBased on fugitive dust losses at 0.05% of coal loaded and U.S. EPA 1980 model year heavy diesel truck allowable emission levels.

^cBased on 1980 model year heavy diesel truck allowable emission levels.

SOURCES: Bechtel Corporation, "Energy Supply Planning Model," Vol. I, 1975, and revisions, 1978.

FIDCo, Inc., "Environmental Assessment of Coal Transportation," 1978.

U.S. Environmental Protection Agency, "Compilation of Air Pollutant Emission Factors, Third Edition," AP-42, 1978.

Slurry Pipeline

ENERGY SYSTEM:

- SIZE** = 1,355 mile pipeline with a 100 foot right-of-way (this based on the slurry pipeline between proposed ERI, Inc., Wyoming and Arkansas)
- annual capacity is 25.0×10^6 tons of coal (472.5×10^{12} Btu)
 - 98% efficiency losses due to reduction of coal heating value because of its slurry water content (5)
 - 36 inch diameter pipe
 - ratio of solids to water (in terms of volume) is approximately 50-50 $\pm$ 5%

DESCRIPTION

- Slurry pipeline transport pulverized coal suspended in water or oil. The system described in this sheet uses water to transport coal. Pipelines using oil to move coal are under study. Coal moved by slurry pipeline must be processed to obtain the proper particle size. Pumping stations, dewatering facilities and (in some cases) storage facilities are also required.

COMMENTS

- pipeline
- pumping stations
- dewatering facilities
- slurry preparation facility

ENVIRONMENTAL CONCERNS

- substantial water requirements
- disposal of waste water at end-of-line (water may be passed through power plant cooling system prior to discharge)

RESOURCES USED:

(Per 10^{12} Btu Transported Annually)

FUEL	
coal transported	32,910 tons
energy content	9,450 Btu/lb

ENERGY	kWh
electricity	1.8×10^7

LAND (1)(2)	Acres
pipeline, right-of-way	33.4
pumping stations	1.79
dewatering facilities	0.11
slurry preparation facility	0.11

WATER	Acres-ft
consumptive	38.87 (3)

MATERIALS (4)	Tons
aluminum	1.34
brass & bronze	0.40
chromium	0.30
concrete	3,016.93
copper	4.43
iron	36
manganese	9.62
nickel	0.03
steel	1,393.98

COSTS (4)	Dollars (1979)
construction	
pipeline (1,355 miles)	2,100,000
coal slurry preparation	300,000
dewatering	15,000
total	2,640,000
operation & maintenance	180,000

PERSONNEL (3)	Workers
construction (3)	12.3
operation & maintenance	0.00224

RESIDUALS & PRODUCTS:

(Per 10^{12} Btu Transported Annually)

AIR POLLUTANTS	
The amount of any pollutant emitted, if any, is unknown.	

WATER POLLUTANTS
After coal slurry has been dewatered, waste water containing suspended coal particles remains to be disposed of. With an open system, disposal of the waste water could cause problems. These could be mitigated by evaporating the water in ponds, or passage through power plant cooling system prior to treatment and discharge.

ENERGY PRODUCT

transported coal	32,910 tons
energy content	9,260 Btu/lb

- (1) Land use value represents land committed to use for the facility divided by annual throughput.
- (2) Based on Bechtel figures for a 36-inch pipeline system with a capacity of 25 million tons/year, and scaled up from 150 miles to 1,355 miles.
- (3) Based upon 1×10^{12} Btu = 32,910 tons of Western subbituminous coal.
- (4) This represents total construction value divided by annual throughput.
- (5) This efficiency refers to the dissipation in the energy content of the coal from entry to exit at the pipeline.

SOURCES: Bitume Associates, Environmental Impacts, Efficiency, and Cost of Slurry Pipeline and Bed Sea, Volume 1, 1974.

Bechtel Corporation, Energy Supply Planning Model, 1976.

University of Oklahoma, Energy Alternatives, May, 1975.

U.S. House of Representatives Committee on Science & Technology, Slurry Pipeline - Coal Slurry Pipeline Research & Development, 1976.

U.S. Energy Research and Development Administration, Environmental Development Plan - Coal Extraction, Beneficiation & Transportation, 1977.

FEDCO, Inc., Environmental Assessment of Coal Transportation, 1978.

High Voltage Transmission

ENERGY SYSTEM:

- SIZE** • 345 KV AC line, 300 miles long
 • right-of-way (ROW) width-150 ft.
 (18 acres/mile)
 • single circuit, 3 conductors
 • carries 600 MW of power plant capacity
 • 82% efficiency
 • total annual input is 11.7×10^{12} Btus
 (3.4×10^9 kWh)
 • total annual output is 9.6×10^{12} Btus
 (2.8×10^9 kWh)

DESCRIPTION

- 345 KV lines are considered high voltage transmission and are more energy efficient than the more common 230 KV lines. The conductors are made of stranded aluminum while the ground wires are steel.

COMPONENTS

- conductors
 • conductor towers and insulators
 • land for ROW

ENVIRONMENTAL CONCERNS

- corona discharge, which may result in radio and TV interference (especially in areas of fringe reception), ozone noise, and production of ozone and NO_x
 • electric and magnetic fields, which may result in fuel ignition by spark discharges, induced electric shock interference with cardiac pacemakers.
 • land usage (However, most ROW land can be put to other uses e.g., agriculture)
 • fuel ignition by spark discharges

RESOURCES USED:

(Per 10^{12} Btu Produced)

FUEL	kWh
electricity (1)	3.54×10^8
MATERIALS (2)	(equivalent to 1.21×10^{10} Btu)
concrete (including cement)	Tons
steel	2810
copper	2320
aluminum	86.9
manganese	450
chromium	17.6
nickel	1.88
cost from	0.0229
LAND	10.4

right-of-way
 (may be simultaneously used for other purposes)

COSTS

construction (2 years)	Dollars (1978)
labor	
non-manual technical labor	850,000
non-manual non-technical labor	168,000
manual labor	4,320,000
materials	
primary non-ferrous metals	1,560,000
fabricated structural products	2,920,000
other materials	330,000
equipment	1,100,000
other construction costs	8,000,000
total construction	16,100,000
operation and maintenance	
operation	none
maintenance	none
labor	14,800
material	4,480
equipment	813
total operation and maintenance	20,100

PERSONNEL

	Workers -	
	First Year	Second Year
construction (2 years)		
non-manual technical labor		
civil engineers	3.9	2.6
electrical engineers	7.9	5.1
mechanical engineers	1.3	0.83
designers and draftsmen	5.3	3.5
supervisors and managers	1.9	0.83
non-manual non-technical		
labor	4.2	4.2
manual labor		
free workers	16.4	49.7
linemen	13.1	39.4
truck drivers	2.7	8.0
operation and maintenance		
operation	none	
maintenance	0.73	

RESIDUALS AND PRODUCTS:

(Per 10^{12} Btu Produced)

AIR POLLUTANTS

A small amount of chemical oxidants, including some NO_x , but mainly ozone, may be generated by the corona of transmission lines.

NOISE

The corona may cause some audible noise, particularly in foul weather. Noise generated will be barely audible, however, will not be loud enough to cause any hearing damage.

ELECTROMAGNETIC FIELDS

Electric and magnetic fields from 345 KV lines may interfere with a few of the most sensitive types of cardiac pacemakers. Single circuit 345 KV lines have maximum field strengths of 4.5 to 8 KV/meter at three feet above the ground. For field strengths of 6 KV/m or more, annoying transient spark discharges may occur in some circumstances.

ENERGY PRODUCT

electricity 2.93×10^8

- (1) Total electrical input to line to get 10^{12} Btu out at 82% efficiency.
 (2) This is not an exhaustive list of all materials required.

SOURCES: Bechtel Corporation, Energy Supply Planning Model, Volume 1973 and revisions 1978.
 Miller, Morton and Gary Kaufman, "High Voltage Overhead," Environment Magazine, Jan/Feb, 1978.
 Tully, R.A. et al., in Examination of Electric Fields Under EHV Overhead Transmission Lines, EPA, 1977.
 General Electric Company, Assessment of Energy Parks vs. Dispersed Electric Power Generating Facilities, Final Report, Volume 1, 1975.
 NITRE Corporation, Resource and Land Investigations (RALI) Program: Considerations in Evaluating Utility Line Proposals, NITR-6948, 1975.

Very High Voltage Transmission

ENERGY SYSTEM:

- SIZE**
- 500 KV AC line, 500 miles long
 - right-of-way (ROW) width-175 ft. (1) (21 acres/mile)
 - single circuit, 3 conductors
 - carries 1200 MW of power plant capacity
 - 65% capacity factor
 - 92% efficiency (resulting from an energy loss of approximately 22 for every 100 miles of transmission line)
 - total annual input is 23.3×10^{12} Btus (6.8×10^9 Btu)
 - total annual output is 20.8×10^{12} Btus (6.1×10^9 Btu)

DESCRIPTION

- 500 KV lines are considered high voltage transmission and are considerably more efficient than the standard 230 KV lines. The conductors are made of stranded aluminum while the ground wires are steel.

COMPONENTS

- conductors
- conductor towers and insulators
- land for right-of-way

ENVIRONMENTAL CONCERNS

- corona discharge, which may result in radio and TV interference (especially in areas of fringe reception), audible noise, and production of ozone and NO_x
- electric and magnetic fields, which may result in fuel ignition by spark discharges, induced electric shocks, interference with cardiac pacemakers
- land usage (however, most ROW land can be put to other uses e.g., agriculture)
- adverse health effects close to line
- fuel ignition by spark discharges

RESOURCES USED: (Per 10^{12} Btus Produced)

TYPE	MBtu
electricity (1)	3.79×10^6 (equivalent to 1.12×10^{12} Btu)

MATERIALS (2)

TYPE	MBtu
concrete (including cement)	1,812
steel	1,667
copper	127
aluminum	534
manganese	11
chromium	3
nickel	0.1
cast iron	6

LAND (1)

TYPE	MBtu
right-of-way (may be simultaneously used for other purposes)	309.9

CONST.

construction (1 year)(1)

labor	Dollars (1978)
non-annual technical labor	610,000
non-annual non-technical labor	120,000
annual labor	2,690,000

materials

primary non-ferrous metal	MBtu
fabricated structural products	1,610,000
other materials	410,000
equipment	620,000
electrical equipment	620,000
other equipment	1,010,000
other construction costs	11,310,000
total	11,310,000

operation and maintenance

operation	MBtu
maintenance	none
labor	13,740
material	3,040
equipment	1,210
total	17,990

PERSONNEL

construction

	First Year	Second Year
non-annual technical labor		
civil engineers	2.8	1.9
electrical engineers	5.6	3.7
mechanical engineers	1.0	0.7
designers & draftsmen	3.8	2.5
supervisors & managers	0.7	0.4
non-annual non-technical labor	3.8	2.0
annual labor		
electricians	1.2	3.4
iron workers	0.2	27.4
linemen	0.1	24.2
truck drivers & laborers	1.0	5.2
operation & maintenance	none	0.6

RESIDUALS AND PRODUCTS: (Per 10^{12} Btus Produced)

AIR POLLUTANTS

A small amount of chemical oxidants, including ozone O_3 , but mainly ozone, may be generated by the corona of transmission lines.

NOISE

The corona may cause some audible noise, particularly in foul weather. Noise generated will not be loud enough to cause hearing damage, however.

ELECTROMAGNETIC FIELDS

Electric and magnetic fields from 500 KV lines will probably interfere with some cardiac pacemakers. Single-circuit 500 KV AC lines have maximum field strengths of 6 to 7 KV/meter at three feet above the ground. This is strong enough to result in annoying transient spark discharges under some circumstances.

ENERGY PRODUCT

electricity	MBtu
	2.93×10^6

(1) Total electrical input to line to get 10^{12} Btus out at 92% efficiency.
(2) This is not an exhaustive list of all materials required.

SOURCES: Technical Corporation, "Energy Supply Planning Model", Volume I, 1973, and revisions, 1978.
Norman Miller and Gary Kaufman, "High Voltage Overhead", Environment Magazine, Jan/Feb-1978.
R.A. Yell, et al., "An Examination of Electric Fields Below 100 KV Overhead Transmission Lines", EPA, 1977.
General Electric Company, Assessment of Human Health vs. Disposed Electric Power Generation Facilities, Volume I, 1973.
The HYPER Corporation, Resource and Land Investigations (HALI) Program: Considerations in Evaluating Utility Line Proposals, HYR-6948, 1975.

Petroleum

The following should be recognized as limitations of the information provided on the summary sheets of this section:

1. The impacts and costs of oil and gas operations vary widely over the period of development. Typically capital costs will be concentrated in the initial phases of development while operation and maintenance costs and impacts will be spread over a longer period of time. Annualizing costs and impacts over the life cycle of a project ignores the actual pattern in which they occur.
2. The figures presented in the data sheets apply to specific representative cases. The variation around these cases may be quite extensive. Some costs, such as platforms, will vary geometrically rather than arithmetically. Thus, an 18-well platform in 400 feet of water will be much more than twice as expensive than one in 200 feet. Unless production per platform changes in exactly the same proportion, the numbers provided in the data sheets may be unrealistic.
3. The data sheets also do not consider changes in the underlying conditions determining the economic limit for oil and gas development. The rapid escalation of crude oil prices and changes in price/cost relationships will bring formerly uneconomic projects into production. These projects will generally have unit cost characteristics which are very different from the "representative" projects shown on the data sheets. It is likely that for these new projects the costs per 10^{12} Btu produced will be much higher. The estimates of environmental impact also do not include the fact that many of the new projects will have improved environmental control systems which are not yet defined. For example, new steam Enhanced Oil Recovery projects will be required to have air emission levels which are much lower than the national averages shown on the data sheets.

Onshore Oil Exploration - Lower 48 States

ENERGY SYSTEM:

- SIZE**
- 100,000 barrels per field per day ultimate average primary production
 - 36.5×10^6 barrels per field per year
 - 27.24% success ratio
 - 20 successful wells, 53 unsuccessful wells
 - four years before initial production begins
 - 5.8×10^6 Btu's per barrel
 - 212×10^{12} Btus per year ultimate production
 - 30% oil reservoir recovery efficiency

DESCRIPTION

- Regional Surveys
 - Research libraries and state or Federal geology offices for information on rock formations and outcrops
 - Obtain any previous stratigraphic drilling records
 - Examine satellite imagery for potential regions
- Local surveys by geophysicist
 - Magnetometer; sedimentary rocks - low magnetic properties
 - Gravimeter; dense rock increases gravitational pull
 - Seismograph; distance shock waves travel in various strata recorded
- Stratigraphic core tests to examine strata for arrangements and possible traces of oil, gas or fossils
- Secure leases, obtain drilling permits and pay annual rental fee
- Site access; site preparation
- Water availability secured through wells or temporary water lines
- Assemble rig; drill to desired depth
- Conduct logging (electric, etc) analysis as to potential productivity
- If considered profitable, remainder of well cased and Christmas tree installed; if not, well plugged with cement and crimped below ground

COMPONENTS

- Geophysical surveying equipment/satellite imagery
- Bulldozer, backhoe and dump truck
- Temporary water lines
- Rotary drill rig; hoisting, rotary and fluid circulation systems; drill string and bits
- Steeling casing and cement
- Geophysical logging and analysis equipment
- Possible production tubing and Christmas tree

ENVIRONMENTAL CONCERNS

- Possible fracturing or connection of underground aquifers of varying qualities
- Air emissions from drilling rigs and site preparation equipment
- Soil erosion losses and decreased fertility resulting from site access and preparation and possible aquatic sedimentation in nearby streams
- Possible blowout or accidental drill pond release

RESOURCES USED:

(Per 10^{12} Btu Produced)

RESOURCE DEPLETION OF OIL

FIELD RESERVOIR

none

ENERGY (1)

Diesel fuel for exploration drilling

Gallons

7,900

LAND (1)

Temporarily committed
Permanently committed

Acres

2,000

0.24

WATER (1)

drilling fluid

Acres-Ft.

0.0067

MATERIALS (1)

casing and tubing
surface and subsurface equipment
steel casings/rig cement

Tons

8.0

7.3

86.1

20.7

COSTS (1)

exploratory drilling

Dollars - 1978

25,550

16,430

RESIDUALS AND PRODUCTS:

(Per 10^{12} Btu Produced)

AIR POLLUTANTS (1)

NO_x 3.50
CO 0.71
HC 0.26
SO 0.22
Particulates 0.23

Tons

WATER POLLUTANTS (1)

Circulating mud system
water loss
Eroded construction site
sediments
Organics
Dissolved Solids

Tons

minimal

site specific

0.14 - 3.86

neg. - 2,969

SOLID WASTE (1)

Drill cuttings, barite,
bentonite, and phosphate

Tons

13

Note: Please refer to the qualification statements at the beginning of this section on Petroleum.

Onshore Oil Exploration - Lower 48 States (Concluded)

(*) Data values represent total life cycle values divided by ultimate average annual energy output normalized to 10^{12} Btu; i.e., for exploratory drilling fuel requirements = 1,675,350 gallons of diesel fuel (for 73 wells) + 212 (212×10^{12} Btu = ultimate annual production) = 7,900 gallons of fuel/ 10^{12} Btu ultimate production.

SOURCES: American Gas Association, 1969. Gas Engineers Handbook. Industrial Press Inc., New York, New York.
 American Petroleum Institute, 1977. Facts about Oil. API, Washington, D.C.
 American Petroleum Institute, 1979. 1977 Joint Association Survey on Drilling Costs. API, Department of Statistics, Washington, D.C.
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 National Academy of Sciences, 1976. Drilling for Energy Resources. NAS. Washington, D.C.
 Oil and Gas Journal, 1979. U.S. Well Completions.
 University of Oklahoma, 1975. Energy Alternatives: A Comparative Analysis. U.S. Government Printing Office, Washington, D.C.
 University of Oklahoma, 1979. Energy from the West: Energy Resource Development Systems Report. Volume V: Oil and Natural Gas. Science and Public Policy Program. U.S. Environmental Protection Agency, EPA-600/7-79-060a. Washington, D.C.
 U.S. Department of Commerce, 1978. Business Statistics, 1977 Edition. The Biennial Supplement to the Survey Current Business. Compiled by Bureau of Economic Analysis and published by U.S. Government Printing Office.
 U.S. Department of Commerce, 1979. Survey of Current Business, Volume 59, Number 11. Bureau of Economic Analysis.
 U.S. Department of Energy, 1978. Working Draft Environmental Impact Statement, Eastern Gas Shale Project and Possible Resolving Commercialization of the Devonian Gas Shale Resource. Washington, D.C.
 U.S. Department of Interior, 1977. Final Environmental Statement, 1977 Outer Continental Shelf Oil and Gas Lease Sale Offshore the North Atlantic Statement Bureau of Land Management.
 U.S. Environmental Protection Agency, 1978. AP-42. Supplement No. 8 for Compilation of Air Pollutant Emission Factors. Third Edition. Office of Air Quality Planning and Standards. Research Triangle Park, North Carolina.

Offshore Oil Exploration - Lower 48 States

ENERGY SYSTEM:

- SIZE** • 4,000 barrels per platform per day⁽¹⁴⁾
 average ultimate primary production
 • 1,460,000 barrels per platform per year average ultimate primary production⁽¹⁵⁾
 • 15.4% total offshore exploratory success ratio⁽¹⁶⁾
 • 18 successful wells per platform ultimate size⁽¹⁵⁾
 • five exploratory wells drilled; two successful wells and three dry holes⁽⁶⁾
 • Average drilling depth 9,500 feet; many of the wells are deviated^(17,18)
 • 1/3 year of exploratory drilling, then a 2-3 year layover while the development plan is finalized and the production platform constructed, towed to position and installed⁽⁹⁾
 • 5.8×10^5 Btus per barrel
 • 8.67×10^{12} Btus per platform per year
 • 40% oil reservoir offshore recovery efficiency⁽¹⁷⁾

DESCRIPTION^(1,2,4)

- Exploratory permit obtained
- Regional surveys performed
 - Magnetometer; air or ship-borne measurements of changes in earth's magnetic field
 - Gravimeter; variations in gravitational pull of various rock types
 - Natural oil seeps
 - Satellite and infrared imagery
- Local surveys
 - Seismic survey in which reflected and refracted sound waves help elucidate subsurface structures and strata
 - Bottom sampling and coring (500-1000 ft. max); permit required
- Exploratory drilling
 - Obtain leases
 - Rent a drill barge, drill ship, jack-up, semi-submersible or submersible depending on water depth, climatic conditions, seafloor configuration and availability
 - Transport drilling apparatus to location and set up to drill
 - Drill to desired depth, and set and cement casing
 - Log and analyze the well for commercial production
 - If productive, finish casing well, perforate the casing, fracture or acidize if necessary, and install production tubing and temporary Christmas tree
 - If not productive, plug with cement and cement casing 15-ft below seafloor

RESOURCES USED: (Per 10¹² Btu Produced)

RESOURCE DEPLETION OF OIL FIELD RESERVOIR

ENERGY	none
Exploratory drilling fuel (five wells - 25,940 bbl) ⁽⁴⁾	$\text{Btu} \times 10^9$ 17.765
WATER SURFACE AREA LAND USE ^{(a)(9)}	Acres
Jack-ups and drill ships	0.24 - 0.59
Semi-submersible	19.1
If one mile fishing buffer included in permit	237.4

WATER ^{(a)(7,18)}	Barrels
Drilling mud water (fresh or salt) for five wells	77.4
Fresh water requirement for workers	3,513.8
COSTS ^(b)	Dollars - 1978
Cantilever jack-up rig example costs	
Shipyards furnished components	65,000
Bull, cantilever, spud legs	1,833,600
Electromechanical self-elevating system	556,300
Crew quarters and heliport	147,000
Cranes, winches, safety equipment, and other	268,700

Owner-furnished components	
Dredge works	65,500
Prime movers	65,000
Traveling block and derrick	47,200
Other equipment such as mud systems, pipe, casing, and safety equipment	458,100
Total Cost	3,441,400
Drilling Costs ^(a) - two successful wells	413,300
- three unsuccessful wells	490,000
Rig Rental Rate (125 days)	
Shallow water rigs	236,250 - 325,000
Deep water rigs	368,750 - 516,250

PERSONNEL ^{(a)(7,9)}	Workers
Exploratory drilling - jack-up	9.9 - 10.3

OCCUPATIONAL SAFETY^{(c)(16)}

Blowouts	Number .0010
Fatalities	.0001
Injuries	.0008
Fire and Explosions	.0050
Fatalities	.0008
Injuries	.0032
Miscellaneous Accidents	.0026
Fatalities	.0023
Injuries	.0009

RESIDUALS: (Per 10¹² Btu Produced)

AIR POLLUTANTS ^(a)	Tons
NO _x	38.26
CO _x	8.28
Exhaust Hydrocarbons	3.06
Particulates	2.73
SO _x	2.54

WATER POLLUTANTS	
Components of drilling muds listed under solid waste	
Brines during well testing	negligible

SOLID WASTE ^{(a)(9)}	Tons
Drill cuttings - 9,500 foot wells	825.3
Drilling Muds	
Barite (BaSO ₄)	157.9
Bentonite and Attapulgite Clay	19.5
Cauetic Soda	6.2
Aromatic Detergent	0.9
Organic Polymers	1.2
Ferrachrome Lignosulfonate	7.7
Total Drilling Muds	193.3

Note: Please refer to the qualification statements at the beginning of this section on Petroleum.

Offshore Oil Exploration - Lower 48 States (Concluded)

ENERGY SYSTEM:

RESOURCES USED:
(Per 10^{12} Btu Produced)

RESIDUALS:
(Per 10^{12} Btu Produced)

COMPONENTS^(1,2,4)

- Geophysical surveying equipment/satellite imagery, boats and planes
- A drilling barge, drill ship, jack-up, semi-submersible or submersible
- Rotary drill rig: hoisting, rotary and fluid circulation systems
- Drill string and bits and water pumping system
- Steel casing and cement
- Geophysical logging and analysis equipment
- Possible production tubing and Christmas tree

ENVIRONMENTAL CONCERNS

- Oil spills/blowouts
 - Open ocean, temporary impact; nearshore bay or estuary severe impact⁽⁵⁾
 - Chronic leakage around platform localized impact⁽⁶⁾
 - Tanker ballast and tanker waste water pollution could be substantial⁽⁷⁾
- Water pollution caused by possible formation brine discharges released during drilling and pumping, and the disposal of exploratory drilling waste which are only used once^(8,9)
- Fire
- Air emissions from drilling and electric power generation motors

Note: Please refer to the qualification statements at the beginning of this section on Petroleum.

- (a) Data values represent total exploratory values divided by the expected average annual output normalized to 10^{12} Btu; i.e., exploratory drilling fuel requirement (5 wells) = 25,940 bbl of diesel fuel $\times 5.8 \times 10^6$ Btu/bbl = 1.505×10^{11} Btu $\div$ (8.47 $\times 10^{11}$ Btu average annual production) = 17,765 $\times 10^9$ Btu of fuel/ 10^{12} Btu produced. (Note that annualizing ignores the actual pattern on which costs and impacts occur.)
- (b) Example exploratory rig costs are shown to illustrate the capital outlay for the exploratory rig owners. Since many exploratory wells would be drilled for a large number of drilling projects with the same rig, the rig rental rate is included as a more realistic exploratory cost.
- (c) These values encompass injuries and fatalities which occurred during exploration, development and production of offshore facilities between 1970-1977.

- SOURCES: (1) Kash, Don W., L.L. White, K.H. Bergoy, M.A. Chertock, M.D. Devine, R.L. Leonard, S.W. Salmen and S.W. Young, 1973. Energy Under the Ocean. A Technology Assessment of Outer Continental Shelf Oil and Gas Operations. University of Oklahoma Press, Norman, Oklahoma.
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Onshore Primary Oil Extraction - Lower 48 States

ENERGY SYSTEM:

- SIZE:**
- 100,000 barrels per field per day average primary production
 - 36.5×10^6 barrels per field per year
 - 47.1% success ratio
 - 400 producing wells - 250 barrels per well per day
 - 195 dry holes
 - seven years for all drilling and facility construction to be completed
 - 26 year average well life expectancy
 - 5.8×10^6 Btu's per barrel
 - 212×10^{10} Btu's produced per year
 - 30% oil reservoir recovery efficiency

DESCRIPTION

- After exploratory drilling completed, the wells tested, and the data analyzed, a production plan has to be developed and a lease obtained.
- Drilling is carried out according to the production plan and to the desired depth, and the plan is modified if higher or lower pay zones come in or if dry holes are obtained.
- Set and cement casing; log and analyze the strata.
- If productive, finish casing the bottom of the hole, perforate the casing, fracture or acidize if necessary, and install production tubing and Christmas tree.
- If not productive, plug with cement and crimp casing; hole goes.
- After development drilling is complete, dismantle drilling equipment and install gathering pipelines to transport oil from the well site to the field processing facility for gas-water-oil separation.

CONSTRUCTION

- Site access and site preparation equipment; bulldozer, backhoe and dump truck
- Temporary water lines
- Rotary drill rig; hoisting, rotary and fluid circulation systems
- Drilling string and bits
- Steel casing and cement
- Geophysical logging and analysis equipment
- Possible production tubing and Christmas tree

ENVIRONMENTAL CONSEQUENCES

- Possible fracturing or connection of underground aquifers of varying qualities
- Air emissions from drilling rigs and site preparation equipment
- Oil spills or blowouts
- Dry land, relatively easily contained and cleaned up - localized impact
- In or near wetland environments, difficult to contain and clean up - could be substantial impact
- Soil erosional losses and decreased fertility resulting from site access and preparation, and subsequently, possible aquatic sedimentation in nearby water bodies
- Possible accidental drill pond release

RESOURCES USED:

(Per 10^6 Btu Produced based on LHV):

RESOURCE DEPLETION

Average possible yearly depletion of crude oil reservoir recovery efficiency

574,700 barrels

30 percent

ENERGY

Diesel fuel for development drilling⁽¹⁾

Btu's $\times 10^9$
7.55

Operation

Prime Mover Electric Pumps⁽²⁾
Master Treater Separators⁽²⁾

4.32

0.84

LAND

permanently committed

Acres
9.43

WATER

(1)
drilling fluid

Acres-Ft.
0.0482

MATERIALS

(1)
refined products
concrete (mixed)
pipe and tubing
oil country tubular goods
reinforcing bars
pumps and drivers

Tons
3,301.9
94.3
39.6
2,641.5
18.9
15.1

COSTS

(1)
Wood Products 56,000
Chemical & Petroleum Products 924,000
Stone and Clay 364,000
Steel and Iron 2,493,000
Non-ferrous Metals 28,000
Fabricated Products 476,000
Materials Total 4,342,000
Construction & Oil Field Equipment 3,754,000
Holding and General Industrial Equipment 315,000
Electrical and Fabricated Plate Products 364,000
Miscellaneous 1,037,000
Equipment Subtotal 5,470,000
Labor, Overhead & Profit 4,875,000
Total Capital Construction Cost 14,286,000
OPERATION/MAINTENANCE⁽²⁾
Metal Products and Machinery 35,000
Electrical Equipment and Instruments 14,000
Transportation and Miscellaneous 77,000
Total Operation and Maintenance 126,000

PERSONNEL

(3)
construction
operation/maintenance⁽²⁾

Months
13.2
9.7

OCCUPATIONAL SAFETY

(4)
deaths
injuries
workdays lost

Per Year
0.002
0.203
33,745

RESIDUALS

(Per 10^6 Btu Produced)

AIR POLLUTANTS

Site access, site preparation, development drilling, & gathering pipeline system⁽¹⁾
NO_x
CO
HC
SO
Particulates
Annual emissions during production⁽²⁾
NO_x
CO
HC
SO
Particulates

Tons

23.2
5.0
2.9
1.6
1.6
18.6
0.3
10.8
13.6
3.5

WATER POLLUTANTS

circulating and system water loss
eroded construction site sediments

Tons

minimal

SOLID WASTE

(1)
drilling cutting, barite, bentonite and phosphates

Tons

94.6

ULTIMATE AVERAGE FIELD PRODUCTION

crude oil
best estimate

172,400 barrels
 5.8×10^6 Btu/b

Onshore Primary Oil Extraction—Lower 48 States (Concluded)

- (1) Data values represent total life cycle values divided by average annual energy output normalized to 10^{12} Btu.
i.e., development drilling fluid energy requirement = $285,214 \text{ bbl} \div 212$ (average annual energy production in trillion Btu)
 $\approx 5.62 \times 10^{-12}$ Btu/bbl $\approx 7.55 \times 10^{-12}$ Btu/ 10^{-6} Btu produced.
- (2) Data values represent annual values divided by average annual energy output normalized to 10^{12} Btu.
- (3) Average number of construction workers (7 year period) divided by average annual energy output normalized to 10^{12} Btu.
- (4) Data are obtained from information on oil and gas production (University of Oklahoma, 1979).

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Offshore Oil Extraction - Lower 48 States

ENERGY RESERVE

- 1,000 barrels per platform per day average primary production
- 1,400,000 barrels per platform per day average primary production
- 70-75 development well success rate
- 18 development wells would be drilled to efficiently tap the reservoir; all dry holes would also be expected.
- Subsequent to the exploratory drilling, 18 successful oil wells and three dry holes would be drilled during the development phase.
- 18 months to complete drilling.
- Partial production could begin before this time but adequate production would not be achieved until 2,500 feet (12.14) (TVD) ramp of the wells are developed
- 15-20 year well life expectancy
- 2.8 x 10¹² bbls per barrel
- 4.7 x 10¹² bbls per platform per year
- 60% efficiency oil recovery necessary efficiency

DESCRIPTION (1,2,3,4,5,6)

- After exploratory drilling is completed, the wells tested, and the data analyzed, a production plan can be developed and a lease obtained.
- Production platform ordered, fabricated, towed to position, and assembled.
- Horizontal drilling is carried out according to production plan and to the desired depth, and the plan is modified if higher or lower pay zones come in as if dry holes are obtained.
- Test and cement casing; log and analyze the strata.
- If production, finish casing the bottom of the hole, perforate the casing, fracture or acidify if necessary, and install production tubing and Christmas trees as when completion operations.
- If test production, plug with cement and strip casing 15 ft below surface on one for reevaluation of formation water.
- When development drilling is completed, the drilling equipment is dismantled and the production/processing equipment is installed on the same platform.
- Process the oil mixture for sand, water and gas separation.
- Pump surface if the fluid is substantial and pumping successfully enhances, stress sensitive for better picture.

CONSTRUCTION

- 4 permanent drilling and production platform
- Heavy drill rig, hoisting, recovery, and fluid circulation systems
- Drill string and bit, and water pumping system
- Rental casing and cement
- Horizontal logging and analysis equipment
- Production tubing and Christmas trees
- On site separation and processing equipment

ENVIRONMENTAL CONSIDERATIONS

- Oil spill/leakage
- Open water, temporary effects, operations, by an activity - human effort
- Chemical leakage around platform - localized
- Worker behavior and safety have water pollution could be substantial
- Water pollution caused by formation water discharge if not subjected to processes
- Air emissions from drilling and electric power generation equipment

REVENUE DATA

(Per 10¹² bbls Produced)

Revenue potential depletion of crude

Oil revenue necessary efficiency

Revenue

Development drilling (18 success)

Oil value - 1 day hole (18)

Operation and maintenance (18)

Prime power pumps

Master transfer (35 bbls)

Other production and support requirements

Water surface area (10¹² bbls)

Drilling platform

If one mile fishing buffer included in revenue

Water

Drilling and water (fresh or salt) - 15 wells

Peak water requirement for water

Materials

Concrete

Reinforced concrete

Steel

Copper, aluminum, magnesium, nickel, and chromium

Iron, steel, aluminum and bronze castings

Structural steel and steel plates

Pipe, tubular goods, and valves

Costs

Platform (4)

Materials for 4,000-ton steel platform

Offshore installation cost

Drilling and lifting equipment

Cement/marble cap/marble/marble

Marine crane/marble/marble/marble

Control

Other - completion equipment, oil and gas treating, separation, heat exchangers, firefighting equipment, large pumps, valves, derrick barges, etc.

Drilling 18 successful oil wells (4)

Three dry holes (1)

Annual operating costs (4)

Lease, supervision, and payroll overhead

Road and transportation

Surface equipment and operating supplies

Wachmen

Communication/administration/insurance

Revenues

Development drilling and production equipment installation

Production (4)

Production (4)

Production (4)

Production (4)

Production (4)

Production (4)

Production (4)

Production (4)

Production (4)

Production (4)

Production (4)

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Production (4)

REVENUE DATA

(Per 10¹² bbls Produced)

ATB PLATFORMS

Development drilling (4)

Oil

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Note: Please refer to the qualification statements at the beginning of this section on Petroleum.

Offshore Oil Extraction - Lower 48 States (Concluded)

- (a) Data values represent total life cycle values divided by average annual energy output normalized to 10^{12} Btu; i.e., development drilling fuel requirement (10^6 wells) = $58,555$ Bbl. of diesel fuel = 3.8×10^6 Btu/585 = 5.7179×10^{11} = 5.72 (8.47 $\times 10^{11}$ Btu average annual production) = $67,508 \times 10^6$ Btu's of fuel/ 10^{12} Btu produced. (Note that annualizing ignores the actual pattern on which costs and impacts occur.)
- (b) Data values represent annual values divided by average annual energy output normalized to 10^{12} Btu.
- (c) These values encompass injuries and fatalities which occurred during exploration, development and production of offshore facilities between 1970-1977.
- (d) Data values represent annual raw upprocessed water pollutants from average Gulf Coast brine concentrations and average brine production per platform, all normalized to 10^{12} Btu.

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Onshore Enhanced Oil Recovery - Steam Injection (Lower 48 States)

ENERGY SYSTEM:

- SIZE:**
- Daily production of enhanced oil recovery 52,650 barrels per day(1)
 - Average heat content 6.3×10^6 Btu/bbl
 - Annual nominal product heat content 84.7×10^{12} Btu
 - Number of wells 1,382(1)
 - Field size 3,434 acres
 - Plant availability 70%
 - Lifetime 15 years
 - Recovery efficiency 10% of GOR(4)
 - Representative oil field Santa River, California (Garry)(1)

DESCRIPTION

- Steam drive is a thermal enhanced oil recovery method where steam is continuously injected through special wells. Due to changes in viscosity and volume (expansion) of oil and possible permeability of rock oil is displaced by water originated from condensed steam. The recovered oil, water, gas mixture is treated in a separation unit.

COMPONENTS

- drill rig
- pipe and casing
- pumps and drivers
- water softeners
- steam boilers
- lime and wellhead insulation
- water knock out tanks (separators)

ENVIRONMENTAL CONCERNS

- air emissions from boilers and heaters (separators)
- fugitive emissions from well heads, oil/water separators, valves, pumps, and storage tanks
- oil and grease spills
- releases of HC and H_2S during oil production
- potential subsidence and seismic activities

RESOURCES USED: (Per 10^{12} Btu Produced)

RESOURCE DEPLETION

crude oil 150,700 barrels
average heat content 6.3×10^6 Btu/bbl

LAND

permanently committed
oil field site(1)

WATER

process steam (4)

MATERIALS

total construction costs(3)
concrete 1,304
total steel 921
oil country tubular goods 460

COSTS

total construction costs(3)
manpower 4.4×10^6
materials 2.12×10^6
equipment $.37 \times 10^6$
other 1.96×10^6
total capital costs(3) 8.35×10^6
operation and maintenance(3) 1.13×10^6

PERSONNEL

construction(3) 3.3
operation(3) 9.1

Acres

41.4

Acres-Ft.

101.3

Dollars (1978)

4.4×10^6

2.12×10^6

$.37 \times 10^6$

1.96×10^6

8.35×10^6

1.13×10^6

Manhours

3.3

9.1

RESTORABLE AND PRODUCTS: (Per 10^{12} Btu Produced)

AIR POLLUTANTS (see text)

particulates(4) 24
SO₂(4) 207
NO_x(2,4) 71
CO(4) 2.9

WATER POLLUTANTS

W(1)

0.3 - 1.9

SOLID WASTE

sludge (waste water treatment)

sludge (SO₂ scrubbers)

PRODUCT

crude oil 150,700 bbl
average heat content 6.3×10^6 Btu/bbl

tons

24

207

71

2.9

4.1

tons

0.3 - 1.9

tons

quantity is process and site specific

*Total plant land, construction cost, materials, or man power divided by the annual output in trillion Btu (70% availability rate).

SOURCES: (1) Newman, R., "Onshore Marine Enhanced Oil Recovery", *Oil and Gas Journal*, 1978.

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Note: The project selected for analysis is the largest project in operation, thus, factors based on this project may not provide average estimates.

Note: Please refer to the qualification statements at the beginning of this section on Petroleum.

Oil-Fired Steam Electric Power Plant

ENERGY SYSTEM:

(4)(c)(4)

- SIZE**
- 800 Mw output
 - thermal efficiency 34.72
 - heat rate 9,800 Btu/kwh
 - capacity factor 55%
 - equipment lifetime 25 years
 - net electrical energy produced 13.15 x 10¹² Btu/year

DESCRIPTION:

- Oil-fired steam electric power plants generate electricity using the same basic unit processes as the other fossil fueled power stations, i.e. coal and natural gas. The chemical energy in the fuel oil is converted to heat energy in the steam generator and again converted to mechanical energy in the turbine. This energy is finally transformed to electrical energy by the generator.

COMPONENTS:

- fuel oil handling, storage and feed system
- steam generator (boiler)
- steam turbine
- generator
- environmental control system - ESP, SO₂ scrubber
- boiler feed water treatment system
- condenser
- water cooling system
- waste water treatment system
- ash removal system
- sludge dewatering system
- solid waste disposal system

ENVIRONMENTAL PROBLEMS:

- air emissions - particulates, SO₂, NO_x
- chemical effluents in wastewater
- thermal discharge
- solid waste disposal
- release of toxic substances
- water use

RESOURCES USED:

(Per 10¹² Btu equivalent electricity produced)

FUEL	
residual oil No. 6	469,500 barrels
heat content	146,000 Btu/gallon
OIL ANALYSIS	
carbon	87.5 - 88.4
hydrogen	10.3 - 12.0
sulfur	0.2 - 4.0 (1.0)
oxygen	0.6 - 1.0
nitrogen	0.3 - 0.5
moisture	0.1
ash	0.03 - 1.0 (0.5)

ENERGY

(Requirements for pollution control devices)

FED	3.5 - 4.0
mechanical collectors	0.2 - 0.9
ESP	0.3
combustion modifications (NO _x)	0 - 0.6
waste water treatment plant	0.1
mechanical draft	2.5
noise control	<0.1

LAND

Active	
plant area	6-12 (6)
evaporative cooling towers,	
mechanical draft	0.6 - 1.4
natural draft	0.1 - 0.4
Active/Year	
incremental area	0.3
surface storage piles	
landfill	highly variable
evaporation ponds	NA

WATER

Active-Fr./Year	
once-through	750
evaporative cooling towers	
mechanical draft	<350
natural draft	<350

CONVE

Dollars (1978)	
construction	
labor	\$5,360,000
materials	1,370,000
equipment	6,530,000
other construction	3,970,000
land & land rights	90,000
general plant	480,000
total	18,000,000
operation and maintenance	
labor	240,000
materials	97,000
equipment	72,000
utilities	73,400
annual operating cost	482,000

RESIDUALS AND PRODUCTS:

(Per 10¹² Btu equivalent electricity produced)

AIR POLLUTANTS (g/N)		Cross	Revised MSRs
TSF	410		43
particulates/arsenic	0.00963		
particulates/beryllium	0.00769		
particulates/cadmium	0.286		
particulates/lead	0.00154		
particulates/mercury	0.00963		
particulates/nickel	2.88		
particulates/manganese	0.00963		
particulates/chromium	0.0228		
particulates/copper	0.0228		
particulates/vanadium	0.0455		
SO ₂	3270		327
NO _x	432		
HC	9.80		
CO	49.3		
WATER POLLUTANTS (fr)		Open	Closed
alkalinity	26.9	Cycle (Yr)	Cycle (Yr)
acidity	52.4		27.3
BOD	0.397		0
COD	34.4		5.16
TSS	69.2		38.7
TDS	109		69.2
ammonia	0.0743		385
nitrate	0.405		0.0743
phosphate	0.0445		0.405
sulfate	284		0.0445
chloride	31.4		284
aluminum	9.88		31.4
chromium	0.0313		9.88
copper	0.417		0.0313
iron	0.663		0.417
magnesium	6.19		0.663
nickel	4.37		6.19
zinc	0.487		4.37
sodium	83.1		0.487
surfactants	135		83.1
antimony	0.00394 - 0.0216		135
arsenic	0.00773 - 0.00134		
benzene	0.0000174 - 0.000836		
beryllium	0.000522 - 0.0139		
cadmium	<0.0000346		
chloroform	<0.201		
cyanogen	0.00948 - 0.000209		
lead	0.00000877 - 0.000507		
mercury	0.0154 - 0.0128		
phenol	0.0640 - 0.000122		
selenium			
toluene			

Note: Please refer to the qualification statements at the beginning of this section on Petroleum.

Oil-Fired Steam Electric Power Plant (Concluded)

ENERGY SYSTEM

RESOURCES USED
(Per 10¹² Btu equivalent
electricity produced)

RESIDUALS AND PRODUCTS:
(per 10¹² Btu equivalent
electricity produced)

PERSONNEL (d)

	First Year	Second Year	Months/Year Third Year	Fourth Year	Fifth Year
construction					
commercial technical	3.6	4.9	6.8	4.7	2.5
noncommercial nontechnical	0.8	2.4	3.3	2.3	1.2
manual	0	20.5	47.9	7.8	20.5
total	2.4	27.8	58.0	14.9	24.2
operation and maintenance					
commercial technical		2.4			
noncommercial nontechnical		2.3			
manual		5.8			
total		11.0			
OCCUPATIONAL SAFETY (e)					
deaths		0.00181			
injuries		0.173			
workdays lost		7.20			

SOLID WASTE (Tons)^(h)

	Without Scrubbers	With Non-Regenerative limestone scrubbers ^(g)
scrubber sludge	0	16,000
400 water		
400 dry solids		
fly ash	370	370
(100% dry solids)		
total solid waste	370	16,370

HEAT (c)

	Btu/Year
stack loss	0.40 x 10 ¹²
cooling water loss	
+ miscellaneous	
station losses	1.48 x 10 ¹²

ENERGY PRODUCT

	Btu-Year ^(f)
electricity	2.33 x 10 ¹⁸

ENVIRONMENTAL CONTROL COSTS^(d)

	Dollars (1978) ^(g)
capital costs -	
central treatment plant	8 44,700
ash transport treatment	28,000
area runoff treatment	18,000
condenser cooling	8,500
water treatment (or)	
cooling tower blowdown	6,000
treatment	
cooling system	
once-through (or)	391,000
evaporative cooling	
towers	
mechanical draft (or)	753,000
natural draft	1,190,000
flue gas desulfurization	1,900,000
system	
ESP	123,000 - 701,000
operation and maintenance costs -	
central treatment plant	20,400
ash transport treatment	25,000
area runoff treatment	700
condenser cooling water	
treatment (or)	1,000
cooling tower blowdown	
treatment	1,000
cooling system	
once-through (or)	1,000
evaporative cooling	
towers	
mechanical draft (or)	4,000
natural draft	2,000
flue gas desulfurization	
system	632,000

^(a) Costs applicable to new equipment, not retrofit cases.

^(b) Assume 2.0 percent sulfur, 90% removal efficiency.

- SOURCES: (a) EPA Development Document for Proposed Effluent Limitation Guidelines and New Source Performance Standards for the Steam Electric Power Generating Point Source Category, March 1974 and October 1974.
(b) EPA, Technical Report for Revision of Steam Electric Effluent Limitations Guidelines, September 1973.
(c) Tebken, Water Pollution Control for the Steam Electric Power Industry, Vol. 1, 1973.
(d) Bechtel Corporation, "Energy Supply Planning Model," 1978.
(e) EPA, Compilation of Air Pollutant Emission Factors, 1977.
(f) Nittman, Trace Toxic Pollutant Coefficients for Energy Supply and Conversions, 1977.
(g) University of Oklahoma, Energy Alternatives: A Comparative Analysis, 1975.
(h) Federal Register, Vol. 44, No. 113, Rules and Regulations, 1979.
(i) Code of Federal Regulations, Title 40, Part 1400 (as mod.)
(j) DOE/EPA, Energy Consumption of Environmental Controls: Fossil Fuel, Steam Electric Generation Industry, 1977.
(k) Petroleum Refinery Engineering, W.L. Malone, McGraw-Hill, 1958.
(l) Nittman, Environmental Impacts, Efficiency, and Cost of Energy Supply and Use, 1974.

Note: Please refer to the qualification statements at the beginning of this section on Petroleum.

95

SIZE = 60 million barrels
= Energy Storage: 336×10^{12} Btu

- The salt dome caverns are created by leaching with water; the resulting brine is discharged into a large body of water such as the Gulf of Mexico in an environmentally acceptable manner. These caverns are provided with a cemented casing to protect subsurface water quality and with pipelines to handle water/brine and crude oil.

- salt dome caverns
- a major body of water nearby
- water withdrawal and brine discharge system
- crude oil delivery and handling system

- discharge of brine and its impact on environment/ecology
- risk of oil spills and associated hazards
- hydrocarbon emissions
- fugitive dust during construction
- emissions from construction vehicles

ENERGY REQUIREMENT
electrical power to
operate pumps

negligible

pipelines, site facilities
and brine disposal
pipelines right of way

ACF9

1.6

0.8

WATER REQUIREMENT
initial leaching operation
56,250,000 gallons
each pumping (crude withdrawal)
operation

Acro-Pt.

173

24

COSIS
construction of total system
operation and maintenance

Dollars (1976)

230,000

not available

PERSONNEL
construction
operation and maintenance

Man-Years

0.6

not available

RESIDUALS IN AIR
hydrocarbons (b)

Tons
2.27

hydrocarbons

Tone
not available

initial leaching operation
each crude oil filling
operation

Acro-Pt.
196

21

negligible during operation

negligible

crude oil quantity stored

Barrels
178,572

178,572

SOURCES: (a) Petroleum Storage for National Security, 1975. National Petroleum Council, Washington, D.C.

(b) Strategic Petroleum Reserve, 1977. Supplement Final Environmental Impact Statement. West Hackberry Salt Domes. NTIS, PB-265-796.

Note: Please refer to the qualification statements at the beginning of this section on Petroleum.

Natural Gas

The following should be recognized as limitations of the information provided on the summary sheets of this section:

1. The impacts and costs of oil and gas operations vary widely over the period of development. Typically capital costs will be concentrated in the initial phases of development while operation and maintenance costs and impacts will be spread over a longer period of time. Annualizing costs and impacts over the life cycle of a project ignores the actual pattern in which they occur.
2. The figures presented in the data sheets apply to specific representative cases. The variation around these cases may be quite extensive. Some costs, such as platforms, will vary geometrically rather than arithmetically. Thus, an 18-well platform in 400 feet of water will be much more than twice as expensive than one in 200 feet. Unless production per platform changes in exactly the same proportion, the numbers provided in the data sheets may be unrealistic.
3. The data sheets also do not consider changes in the underlying conditions determining the economic limit for oil and gas development. The rapid escalation of crude oil prices and changes in price/cost relationships will bring formerly uneconomic projects into production. These projects will generally have unit cost characteristics which are very different from the "representative" projects shown on the data sheets. It is likely that for these new projects the costs per 10^{12} Btu produced will be much higher. The estimates of environmental impact also do not include the fact that many of the new projects will have improved environmental control systems which are not yet defined. For example, new steam Enhanced Oil Recovery projects will be required to have air emission levels which are much lower than the national averages shown on the data sheets.

Onshore Gas Exploration - Lower 48 States

ENERGY SYSTEM:

- SITE** (1,2,3,4,5,6,7,8)
- 20-6 x 10⁶ cu ft gas per well field per day average ultimate production (1,2,7)
 - 10,811 x 10⁶ cu ft gas per field per year average ultimate production (1,2,7)
 - 21,342 success ratio (2)
 - 130 successful wells per field ultimate size (8)
 - Twenty-eight exploratory wells drilled; 6 successful and 22 unsuccessful wells drilled (2)
 - One to one and a half years of drilling and analysis before a decision is made on production
 - Average drilling depth 3,000 ft (6)
 - Well life expectancy 15-25 years (3)
 - 1000 ft gas per acre cubic foot of gas
 - 70 percent (50-90%) gas reservoir recovery efficiency (3)
 - 10,811 x 10¹² btus per field per year ultimate production

REQUIREMENTS

- Regional surveys (4)
 - Research libraries and state or Federal geology offices for information on rock formations and outcrops
 - Obtain any previous stratigraphic drilling records
 - Examine available imagery for potential regions
- Local surveys by geophysicist (4)
 - Magnetometer; sedimentary rocks - low magnetic properties
 - Gravimeter; same rock increases gravitational pull
 - Seismograph; distance about waves travel to various strata recorded
- Stratigraphic core tests to examine strata for arrangement and possible traces of oil, gas or fossils (4)
- Secure leases, obtain drilling permits and pay annual rental fee (4)
- Site access; site preparation (1)
- Water availability secured through wells or temporary water lines (1)
- Conduct logging analysis to determine potential productivity (1)
- If considered profitable, remainder of well cased and Christmas tree installed; if not, well plugged with cement and crimped below ground (1)

COMPONENTS

- Geophysical surveying equipment/ satellite imagery
- Drilltower, hoists and derrick truck
- Temporary water lines
- Rotary drill rig; hoisting, rotary and fluid circulation systems; drill string and bits
- Fluid casing and cement
- Geophysical logging and analysis equipment
- Possible production tubing and Christmas tree

ENVIRONMENTAL CONCERNS

- Possible fracturing or connection of underground aquifers of varying qualities
- Air emissions from drilling rigs and site preparation equipment
- Soil erosion losses and decreased fertility resulting from site access and preparation and possible aquatic contamination in nearby streams
- Possible blowout, fire or accidental drill pond release

REQUIREMENTS

(Per 10¹² btus Produced)

RESOURCES EXPLORATION OF OIL FIELD RESERVOIR

WELLS (9,10,11,12,6)

Exploratory drilling fuel (28 wells - 24,750 bbl diesel)^a

Gas processing fuel requirement

LAND (13)

Well pads and access roadways^a

WATER (13)

Drilling mud field (28 wells)^a

MATERIALS

COSTS (6)^b

Drilling costs

6 successful gas wells^a

22 unsuccessful dry holes^a

PERSONNEL (11,11)

Construction and drilling requirements (28 wells)^a

Site access

Site preparation

Well drilling

Perforation and cementing

Site cleanup

OCCUPATIONAL SAFETY (15)^c

Fatalities

Injuries

Non-days lost

None

See 10¹²

13,278

None

Acrea

7.34

Barrels

16,310

W/A^b

None

None

None

None

None

None

None

None

None

None

None

None

None

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None

RESOURCES AND PRODUCTS

(Per 10¹² btus Produced)

AIR POLLUTANTS (14,11,11,10)^a

Exploratory drilling/site prep

NO_x

CO

HC

SO_x

Particulates

WATER POLLUTANTS

Spills during well hunting

SOLID WASTE^a

Drill cuttings (28-3000 ft wells)^a

None

23.8

5.2

1.9

1.6

1.7

None

None

None

None

None

None

None

None

None

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Note: Please refer to the qualification statements at the beginning of this section on Natural Gas.

Onshore Gas Exploration - Lower 48 States (Concluded)

*Data values represent total exploratory values divided by the expected average annual output normalized to 10^{12} Btu; i.e., exploratory drilling fuel requirement for 28-5000 ft wells = 24,750 bbl of diesel fuel $\times 3.8 \times 10^6$ Btu/bbl = 1.4355×10^{11} Btu $\div 10.811$ (10.811 $\times 10^{12}$ Btu average annual production) = 13.178×10^6 Btu of fuel/ 10^{12} Btu produced.

*Material and cost data for onshore gas is derived from the Bockel Corporation (1976) study; however, they did not separate their exploratory material and cost data from their development material and cost data and, consequently, the exploratory values are a portion of those listed under the extraction/production phase. Sample drilling costs are included for informational purposes only as they would also be included in the extraction/production phase. These values are industry values which have been previously normalized to 10^{12} Btu.

*Calculated assuming the following bore hole sizes: 18 inches for 100 ft, 11 3/4 inches for 1800 ft, and 8 3/4 inches for 3100 ft and an average rock density for limestones, clays, and shales of approximately 1.5 grams per cubic centimeter.

- SOURCES:
- (1) University of Oklahoma, 1979. "Energy From the West: Energy Resource Development Systems Report." Volume V. Oil and Natural Gas. Science and Public Policy Program/University of Oklahoma. U.S. Environmental Protection Agency, EPA-600/7-79-060a, Washington, D.C.
 - (2) Oil and Gas Journal, November 11, 1979. "U.S. Well Completions". Oil and Gas Journal, Volume 77, Number 44.
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 - (5) American Gas Association, 1979. Gas Facts 1978 Data. American Gas Association Department of Statistics, Arlington, Virginia.
 - (6) American Petroleum Institute, 1979. 1977 Joint Association Survey on Drilling Costs. Washington, D.C.
 - (7) Bockel Corporation, 1976. The Energy Supply Planning Model. San Francisco, California.
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 - (12) U.S. Department of Energy, 1978. Working Draft Environmental Impact Statement. Eastern Gas Shale Project and Possible Mining Commercialization of the Western Gas Shale Resources. Washington, D.C.
 - (13) U.S. Federal Power Commission, 1973. "Natural Gas Survey". Volume II. U.S. Government Printing Office, Stock Number 1500-00250. Washington, D.C.
 - (14) U.S. Environmental Protection Agency, 1978. AP-42, Supplement No. 9 for Compilation of Air Pollutant Emission Factors. Third Edition. Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina.
 - (15) Riles, C. P., Clifford, E., Golgruben, E., Graf-Schuster, E., Eichenberger, E., Hehr, H., Stimmer, 1977. Accidents and Uncontrolled Events Associated with Non-Hydrocarbon Energy Resources and Technology. U.S. Environmental Protection Agency - Office of Energy, Minerals, and Industry. EPA-600/7-77-012.

Offshore Gas Exploration - Lower 48 States

ENERGY SYSTEM:

(2,4,6,13,14,15,16,17)

- 80,722,000 cubic feet of gas per platform per day, average ultimate conventional production⁽¹⁴⁾
- 3,238 ± 1030 cubic feet of gas per platform per year, average ultimate conventional production⁽¹⁵⁾
- 13.45 exploratory wells success ratio⁽¹³⁾
- five exploratory wells drilled; two successful wells and three dry holes⁽⁴⁾
- 1/3 year of exploratory drilling, then a 2-3 year layover while the development plan is finalized, and the production platform constructed, moved to position and installed⁽⁵⁾
- Average total vertical depth (TVD) 9,400 feet; many of the wells are deviated^(14,15)
- 1000 ft per cubic foot of gas
- 31,384 x 10¹¹ Btus per platform per year, average ultimate conventional production
- 50-90 percent gas reservoir recovery efficiency⁽¹⁷⁾

DESCRIPTION (1,3,4,7,8,9)

- Exploratory permit must be obtained
- Regional surveys made:
 - Magnetometer; air or ship-borne measurements of changes in earth's magnetic field
 - Gravimetry; variations in gravitational pull of various rock types
 - Natural oil seeps
 - Satellite and infrared imagery
- Local surveys made:
 - Seismic survey in which reflected and refracted sound waves help elucidate subsurface structures and strata
 - Bottom sampling and coring (500-1000 ft. max); permit required
- Exploratory drilling activities performed:
 - Obtain lease
 - Rent a drill barge, drill ship, jack-up, semi-submersible or submersible depending on water depth, climatic conditions, seafloor configuration and availability
 - Transport drilling apparatus to location and set up to drill
 - Drill to desired depth, seal and cement casing
 - Log and analyze the well for commercial production
 - If productive, finish casing well, perforate the casing, fracture or acidize if necessary, and install production tubing and temporary Christmas tree
 - If not productive, plug with cement and crimp casing 15-ft below seafloor

COMPONENTS (3,4,6)

- Geophysical surveying equipment/satellite imagery, boats and planes
- A drilling barge, drill ship, jack-up, semi-submersible or submersible
- Rotary drill rig; hoisting, rotary and fluid circulation systems
- Drill string and bits, and water pumping system
- Steel casing and cement
- Geophysical logging and analysis equipment
- Possible production tubing and Christmas tree

ENVIRONMENTAL CONCERNS

- Possible blowouts and fires
- Water pollution from formation brine discharges released during drilling and pumping operations (if not reinjected), and the disposal of exploratory drilling waste which are only used once^(11,12)
- Air pollution from drilling and electric power generation motors

RESOURCES USED:

(Per 10¹¹ Btu Production Potential)

RESOURCE DEPLETION OF GAS FIELD RESERVOIR

RECOVERY (3,4,6,22,23)
Exploratory drilling fuel - five wells⁽⁴⁾

WATER SURFACE AREA LAND USE (a)(11)
Jack-up and drill ships
Semi-submersible
If one mile fishing buffer included in permit

WASTE (a)(9,30)
Drilling and water (fresh or salt) for five wells
Fresh water requirement for workers

NOISE (a,b)(9,14,15)
(These are cantilever jack-up rig example costs)

Shipyards furnished components
Ball, cantilever and speed legs
Electromechanical self-elevating system
Crew quarters and hallways
Cranes, winches, safety equipment and other
Owner furnished components
Dismantle
Prime movers
Towering block and derrick
Other equipment such as mud system, pipe, casing and safety equipment

Total Cost
Rig Rental Rate (125 days)
Shallow water rigs
Deep water rigs
Drilling Cost - two successful gas wells^(14,15)
- three dry holes

PERSONNEL (a)(9,11)
Exploratory drilling - jack-up rig

OPERATIONAL SAFETY (C)(19)

Blowouts
Fatalities
Injuries
Fires and Explosions
Fatalities
Injuries
Miscellaneous Accidents
Fatalities
Injuries

RESIDUALS:

(Per 10¹¹ Produced)

AIR POLLUTANTS (a)(5,6,9,21,22,23)

Exploratory drilling
H₂
CO^{*}
Exhaust Hydrocarbons
SO₂
Particulates

WATER POLLUTANTS
Brine during well testing
(Components of the drilling waste are listed under solid waste)

SOLID WASTE (a)(11)
Drill cuttings - 9,400 foot wells
Drilling waste
Barite (BaSO₄)
Bentonite and Arctamagite Clays
Caustic Soda (NaOH)
Aromatic Reserpent
Organic Polymers
Pentachloro Lignosulfonates
Total Drilling Waste

negligible

Btu x 10⁹

4,644

Acres

561 ± 154

62.10

Barrels

20.2

919.0

Dollars - 1978

145,500

38,480

70,300

16,900

17,000

12,400

119,800

\$ 899,300

\$41,000 - \$84,900

\$94,500 - \$135,000

\$106,700

\$128,200

Marine

2.39 - 4.49

Number of Accidents or Injuries

.0010

.0001

.0008

.0050

.0008

.0032

.0026

.0023

.0009

Note: Please refer to the qualification statements at the beginning of this section on Natural Gas.

Offshore Gas Exploration - Lower 48 States (Concluded)

- (a) Data values represent total exploratory values divided by the projected average annual output supplied to 10^{12} Btu; i.e., exploratory drilling (fuel requirement (3 wells) $\times$ 15,000 bbl of diesel fuel $\times$ 5.8 $\times$ 10^6 Btu/bbl $\div$ 31,394 (31,434 $\times$ 10^6 Btu average annual production) = 4.646×10^6 Btu of fuel/ 10^{12} Btu produced. (Note that annualizing ignores the actual pattern on which costs and impacts occur.)
- (b) Example exploratory rig costs are shown to illustrate the capital outlay for the exploratory rig costs. Since many exploratory wells would be drilled for a large number of drilling projects with the same rig, the rig rental rate is included as a more realistic exploratory cost.
- (c) These values encompass injuries and fatalities which occurred during exploration, development, and production of offshore facilities between 1970-1977.

- SOURCES: (1) University of Oklahoma, 1979. "Energy From the West: Energy Resource Development Systems Report." Volume V. Oil and Natural Gas. Science and Public Policy Program/University of Oklahoma. U.S. Environmental Protection Agency, EPA-600/7-79-006, Washington, D.C.
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- (22) Salisbury, J. Kenneth (Ed.), 1967. Engel's Mechanical Engineers' Handbook - Power Volume. Wiley Engineering Handbook Series. John Wiley & Sons, Inc., London, England.
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Onshore Gas Extraction - Lower 48 States

ENERGY SYSTEM:

- SIZE** (1,5,7,10,15,20,30,40)
- 29.4 x 10³ cu. ft. gas per well field per day average production (1,5,7)
 - 10,411 x 10³ cu. ft. gas per well field per year average production (1,5,7)
 - 47,182 average rate (1)
 - 1.43 x 10³ cu. ft. per well per day (3)
 - 120 wells would be drilled to efficiently tap the reservoir; 60 dry holes would also be expected. Subsequent to the exploratory drilling, 114 successful gas wells and 38 unsuccessful dry holes would be drilled during the development stage (2)
 - 3 years for all drilling and facility construction to be completed (1)
 - Average drilling depth 5,000 ft. (6)
 - Well life expectancy 15-25 years (3)
 - 1000 Btus per average cubic foot of gas
 - 78 percent (20-90) gas reservoir recovery efficiency (8)
 - 10,411 x 10³ Btus per field per year

DESCRIPTION (1,4)

- After exploratory drilling completed, the wells tested and the data analyzed, a production plan has to be developed and a lease obtained.
- Drilling is carried out according to the production plan and to the desired depth, and the plan is modified if higher or lower pay zones come in or if dry holes are obtained.
- Set and cement casing; log and analyze the strata.
- If productive, finish casing the bottom of the hole, perforate the casing, fracture or sidetrack if necessary, and install production tubing and Christmas tree.
- If not productive, plug with cement and crimp casing below the ground.
- After development drilling complete, disassemble drilling equipment and install gathering pipeline to transport gas from the well site to the field processing facility for gas-water separation and treatment.

COMPONENTS

- Site access and site preparation equipment; bulldozer, backhoe and dump truck
- Temporary water lines
- Rotary drill rig; hoisting, rotary and fluid circulation systems
- Drill string and bits
- Road casing and cement
- Geophysical logging and analysis equipment
- Possible production tubing and Christmas tree
- Gas processing facility

ENVIRONMENTAL CONCERNS

- Possible fracturing or connection of underground aquifers of varying qualities
- Air emissions from drilling rigs and site preparation equipment
- Soil erosion, leaching and decreased fertility resulting from site access and preparation, and subsequently possible aquatic sedimentation in nearby waterbodies
- Possible blowout, fire or accidental drill pipe release

RESOURCES USED:

(Per 1012 Btu Produced)

RESOURCE DEPLETION

Average potential yearly depletion of gas 15,444 x 10³ cu ft

Gas reservoir recovery efficiency (8) 70 (50-90) percent

ENERGY (9,10,6,11,12,13)

Development drilling fuel (114)

Successful wells plus 38 dry holes - 134,370 bbl diesel^a

Gas Processing Energy Requirement (10)^b

Sweet gas

Sour Gas

LAND (14)

Temporary requirements^a

Permanent requirements^a

WATER (14)

Drilling and field (152 wells)^a

MATERIALS (7)^a

Concrete/cement

Sandstone/bitrite

Steel

Copper, aluminum, manganese & other metals

Steel casings and steel pipe

Pipe, tubular goods, and valves

Drill bits, pumps, compressors and heat exchangers

COSTS (7)

Manpower

Materials (concrete, clay, steel, metals, etc.)

Equipment (electrical, instrumentation, drilling)

Other costs and services (land, construction start-up, interest, etc.)

Total Construction & Drilling Costs^a

Manpower

Materials (chemicals, petroleum products, steel & other metals)

Equipment & fabricated piece products

Other (water, royalties, taxes and services)

Annual Operating Cost^b

PERSONNEL (7)

Technical Manpower

Non-technical, non-technical manpower

Manual manpower

Total Construction Manpower^a

Technical Manpower

Non-technical, non-technical manpower

Manual manpower

Total Annual Manpower^b

OCCUPATIONAL SAFETY (18)^a

Fatalities

Injuries

Man-days lost

RESIDUALS:

(Per 1012 Btu Produced)

AIR POLLUTANTS (10,15,16,12,13,11)

Development drilling/site access & preparation/gathering pipeline system construction^a

NO_x

CO

HC

SO_x

Particulates

Annual production emissions^b

NO_x

CO

HC

SO_x

Particulates

WATER POLLUTANTS (17)

Natural gas processing plants^a

BOD

COD

Oil & Grease

Chlorides

Zinc

TDS

Chloride

Sulfate

SOIL WASTE^a

Drill cuttings (152-5000 ft. wells)^b

AVERAGE FIELD PRODUCTION

Natural Gas

Heat Content

TIME

130.3

28.7

10.6

9.0

9.3

84.7

1.9

0.4

1424.6

1.9

1.71

11.20

34.27

0.09

0.03

456.95

81.68

68.54

1364

1 x 10³ cu.ft.

1000 Btu/scf

Note: Please refer to the qualification statements at the beginning of this section on Natural Gas.

Onshore Gas Extraction - Lower 48 States (Concluded)

^aData values represent total life cycle values divided by average annual energy output normalized to 10^{12} Btu; i.e., development drilling fuel requirement (150-5000 ft wells) = $134,370$ bbl diesel fuel $\times 5.8 \times 10^6$ Btu/bbl = 7.7925×10^{11} Btu + 10.811 (10.811 $\times 10^{12}$ Btu average annual production) = 72.068×10^9 Btu of fuel/ 10^{12} Btu produced. (Note that annualizing ignores the actual pattern on which costs and impacts occur.)

^bData values represent annual values divided by average annual energy output normalized to 10^{12} Btu.

^cThese values are industry values which have been previously normalized to 10^{12} Btu.

^dCalculated assuming the following bore hole sizes: 18 inches for 100 ft, 12 3/4 inches for 1800 ft, and 8 3/4 inches for 3100 ft and an average rock density for limestones, clays and shales of approximately 2.5 grams per cubic centimeter.

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Offshore Gas Extraction - Lower 48 States

SYSTEMS

WELL (1, 6, 8, 9, 13, 14, 15)

- 80,751,000 cu. ft. of gas per platform per day average conventional production
- 1,238 cu. ft. of gas per platform per year average conventional production
- 15-25 development well success ratio (13)
- 15 development wells would be drilled to efficiently tap the reservoir; six dry holes would also be expected. Subsequent to the exploratory drilling, 15 successful oil wells and three dry holes would be drilled during the development phase.
- 1 1/2 years total development drilling time (14)
- Average total vertical drilling depth (TVDD) 9,000 ft.; many of the wells are deviated (15)
- 15-25 year well life expectancy (16)
- 1000 Bbls per cu. ft. of gas
- 20,000 cu. ft. Bbls per platform per year average conventional production
- 10-20 percent gas reservoir recovery efficiency (17)

DEVELOPMENT (1, 3, 4, 5, 8, 9)

- A direct exploratory drilling completed, the wells tested, and the data analyzed, a production plan has to be developed and a lease obtained
- Production platform offshore, fabricated, towed to position, and assembled
- Directional drilling is carried out according to production plan and to the desired depth, and the plan is modified if higher or lower pay zones come in or if dry holes are obtained
- Set and cement casing; log and analyze the screen
- If productive, finish casing the bottom of the hole, perforate the casing, fracture or sidetrack if necessary, and install production tubing and Christmas trees or subsea completion apparatus
- If not productive, plug with cement and casing casing 13 ft. below seafloor or use for reinjection of formation water
- After development drilling complete, disconnect drilling equipment and install production/preventing equipment on the sea platform
- Process the gas for water, hydrogen sulfide, and higher hydrocarbons and pump it ashore thru pipelines

CONCRETE (3, 4, 5)

- A permanent drilling and production platform
- Heavy drill rig; hoisting, rotary and fluid circulation system
- Drill string and bits, and water pumping system
- Steel casing and cement
- Geophysical logging and analysis equipment
- Production tubing and Christmas trees
- On-site operation and processing equipment

ENVIRONMENTAL CONSIDERATIONS

- Possible blowouts and fires
- Water pollution from formation brine, discharges released during drilling and pumping operations (if not sub-permeable)
- Air emissions from drilling and electric power generation sources

RESOURCES USED:

(Per 1012 Site Produced)

RESERVOIR DEPLETION OF GAS FIELD

Average potential yearly depletion of gas 1,429 x 10⁹ cu. ft.
One reservoir recovery efficiency (17) 70 (30-90) percent

WATER (5, 6, 8, 13, 19, 24, 25)

Development drilling (16 successful wells + 3 dry holes) (14, 15)
Operation and maintenance (c) (18, 19)
Gas turbine (3000) for electrical/mechanical use 1,091

WATER SURFACE AREA LAND USE (12)

Drilling platform 100' x 134'
If one mile fishing buffer included in permit 63.10

WATER (9, 23)

Drilling and water (fresh or salt) for aluminum wells (14)
Fresh water requirement for weather (c) 315.3

CRANE (9, 14, 20, 21)

Platform (a)

Platform 1187,400
Labor 222,400
Materials - 5000 ton steel platform 16,800
Offshore installation cost 21,200
Rigging and living quarters 20,500
Communication/cable/pumpout 13,000
Master system/instrumentation/structure 229,400
Other - suspension equipment, oil and gas treating equipment, heat exchangers, fire fighting equipment, barge bums, valves, derrick bums, traps, etc.
Total - platform costs \$751,000
Drilling costs - 15 successful gas wells (a, b) (14, 20) 125,700
+ 3 dry holes 111,700
Total drilling costs (a) (18, 20, 21) \$ 14,700
Annual operating costs (a) (18, 20, 21)
Labor, supervision & payroll overhead 12,700
Food and transportation 2,700
Surface equipment and operating supplies 14,700
Maintenance 14,400
Communication/administrative/insurance \$ 53,400

PRODUCTION (9, 11)

Development drilling and production equipment installation (a) 1.35 - 2.04
Production (c) 8.40

OCCUPATIONAL SAFETY (4) (22)

Blowouts .0010
Fatalities .0001
Injuries .0008
Fires and Explosions .0010
Fatalities .0008
Injuries .0012
Miscellaneous Accidents .0016
Fatalities .0012
Injuries .0009

RESIDUALS:

(Per 1012 Site Produced)

AIR POLLUTANTS (3, 6, 8, 9, 18, 24, 25, 26)

Development drilling (a) 38.03
NO_x 8.23
CO 3.04
Exhaust hydrocarbons 2.53
SO_x 1.72
Particulates 0.1319
Annual estimate during production (c)
NO_x 0.0037
CO 0.0090
Exhaust hydrocarbons 0.0003
SO_x N/A
Particulates 0.0003

WATER POLLUTANTS (a) (27)

Cadmium 0.00429
Cyanide 0.00093
Mercury 38.213
Total organic carbon 6.7544
Total suspended solids 10,138.0
Total dissolved solids 5,644.0
Chlorides 0.0003

SOLID WASTE (a) (11)

Drill cuttings - 9,600 foot wells 117.69
Drilling muds 14.52
Sediment and Arctowalite Clay 4.62
Glastic ends (HCH) 0.66
Aromatic detergent 0.88
Organic polymers 3.72
Petrochemical lignosulfonates 144.09
Total drilling waste

AVERAGE FIELD PRODUCTION

Natural gas 1.0 x 10⁹ cu. ft.
Heat content 1000 Btu/cu ft

Note: Please refer to the qualification statements at the beginning of this section on Natural Gas.

Offshore Gas Extraction - Lower 48 States (Concluded)

- (a) Data values indicate total life cycle values divided by average annual energy output normalized to 10^{12} Btu i.e., development drilling fuel requirement (19 wells) $\times$ 99,945 Btu of diesel fuel $\times$ 5.5 $\times$ 10^6 Btu/Btu $\times$ 17.70 (21,364 $\times$ 10^6 Btu average annual production) = 17,457 $\times$ 10^6 Btu of fuel/ 10^{12} Btu produced.
- (b) Fuel requirements for development drilling include only those wells drilled during development (16 successful plus three unsuccessful); exploratory drilling fuel requirements are accounted for during the exploratory phase. Drilling costs are determined in a similar manner.
- (c) Data values represent annual values divided by average annual energy output normalized to 10^{12} Btu.
- (d) These values encompass injuries and fatalities which occurred during exploration, development, and production of offshore facilities between 1970-1977.
- (e) Data values indicate annual raw unprocessed water pollutants from average Gulf Coast brine concentrations and average brine production per platform, all normalized to 10^{12} Btu. Values for water produced from gas wells were determined from data combining both oil and gas wells.

- SOURCES: (1) University of Oklahoma, 1979. Energy From the West: Energy Resource Development Systems Report. Volume V. Oil and Natural Gas. Science and Public Policy Program/University of Oklahoma. U.S. Environmental Protection Agency, Washington, D.C. EPA-600/7-79-040a.
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- (20) U.S. Department of Commerce, 1979. Overseas. Bureau of Current Business, Volume 29, Number 11. Bureau of Economic Analysis.
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Natural Gas Purification

ENERGY SYSTEM:

- SIZE** (a)(d)
- 250 million scf/D of clean gas output
 - >1,600 Btu/scf
 - operates 328 days per year
 - 90% plant availability
 - plant efficiency 87 to 92%
 - plant life 30 years

DESCRIPTION (a)

- Raw natural gas contains gases and liquids which have to be removed before the natural gas can be placed in the transmission lines. These gases and liquids can include water, hydrogen sulfide, carbon dioxide, nitrogen, and various hydrocarbons such as ethane, propane, butane, and heavier. The purification process incorporates those systems such as dehydration, desulfurization, and carbon dioxide removal (gas sweetening), and natural gas liquids (NGL) separation required to provide a natural gas product suitable for pipeline distribution.

COMPONENTS (a)

- Major equipment consists of contactors, stills, reboilers, heat exchangers, pumps and compressors, plus auxiliary hardware associated with the following processing systems. These processes, which may be utilized either separately or in combination, include the following:
 - Dehydration - can be accomplished by compression, treatment with drying substances such as diethylene glycol, absorption, and refrigeration.
 - Desulfurization - raw gas is usually scrubbed with some sort of aqueous amine solution such as, mono, di or triethanolamine. Additional processes such as the Claus Process may be added to recover sulfur from the hydrogen sulfide off-gas.
 - Natural Gas Liquids Separation - two of the major processes used are refrigerated absorption and low temperature distillation.

ENVIRONMENTAL CONCERNS

- Vent gas from Claus Plant (may require tail gas clean-up facility if emissions exceed applicable regulations).
- Stripper solution vents.
- Condensate stripper bottom disposal.
- Relief valve and vent emissions.
- Make-up water requirements.

(1) Estimated from source (c).

(2) Synthesized from source (a).

(*) Values are annualized per trillion Btu.

SOURCES: (a) Chemical Process Industries, R.H. Shreve and J.A. Brink, Jr., McGraw-Hill, 1977.

(b) Yehoshua, Inc. (Thomas B. Pigford, et al.) Fuel Cycle for Electrical Power Generation, Phase I Toward Comprehensive Standards for Electric Power Plants (NTIS PB 258 523). Office of Research and Monitoring - Environmental Protection Agency, January 1975.

(c) White, L.P. and D.J. Horvath, "Case-Case Plant Boosts CIG's Supply", Oil and Gas Journal, 1979.

(d) Irvin L. Milby and Steven H. Spaw, (Texas Air Control Board), "Pollution Abatement Energy Usage of Gas Treating and Processing Plants," Journal of the Air Pollution Control Association, Volume 27, No. 11, November 1977.

(e) University of Oklahoma, Energy Alternatives: A Comparative Analysis. (U.S. GPO PO41-011-00025-4), (Washington, D.C.: Council on Environmental Quality, May 1975).

(f) Harry Butcher and Tom Labare, "Natural Gas Processing," Compilation of Air Pollutant Emission Factors, Third Edition, (AP-42 Part B). Research Triangle Park, N.C.: U.S. Environmental Protection Agency - Office of Air and Waste Management, August, 1977, pp. 9-2-3.

RESOURCES USED:

(Per 10¹² Btu of clean natural gas produced)

UTILITIES

Soft raw gas requiring sulfur removal and separation of natural gas liquids, i.e. propane, butane, etc. The quantity of raw gas consumed to produce 10¹² Btu of clean natural gas is determined by the overall process efficiency (87 to 92%), and the heating values and quantities of by-products produced (sulfur, propane, butane, etc.).

ENERGY

electricity

NA

LAND (3)

plant

0.275 acres

WATER (1)(3)(c)

boiler make-up

5.0 acre-ft.

COSTS

construction
operation and maintenance

Dollars

NA

NA

PERSONNEL

construction
operation and maintenance

Workers/Year

NA

NA

RESIDUALS AND PRODUCTS:

(per 10¹² Btu of clean natural gas produced)

AIR POLLUTANTS (b)(e)(f)

Particulates
SO₂
HC
CO
Aldehydes

Tons

0.182

40.9

0.0054

0.36

0.0036

0.027

BY-PRODUCT

sulfur
natural gas liquids -
propane, butane, etc.

Tons

NA

NA

ENERGY PRODUCT (a)

clean natural gas

heating value (1)

gas consumption (2)

methane

ethane

propane

butane

pentane

CO₂

H₂

250 million scf/D

1,011 to 1,093 Btu/scf

1 Volume

81 to 94

2.5 to 7.0

0.7 to 2.8

0.2 to 0.6

0.03 to 0.66

0.4 to 1.0

0 to 2.2

Note: Please refer to the qualification statements at the beginning of this section on Natural Gas.

Gas-Fired Steam Electric Power Plant

ENERGY SYSTEM:

- SIZE** • 800 Mw
• thermal efficiency 34.0%
• heat rate 10,000 Btu/kWh
• capacity factor 55%
• equipment lifetime 35 years
• annual net electrical energy production
13.15 x 10¹² Btu/year

DESCRIPTION

- Gas-fired steam electric power plant generates electricity using the steam produced in the boiler, with heat from natural gas combustion

COMPONENTS

- water purification system
- boiler
- condenser
- condenser cooling water system once through (or) cooling towers
- steam turbine
- generator
- central waste treatment plant
- air preheater
- economizer

ENVIRONMENTAL CONCERNS

- air emissions - NO_x
- chemical waste water effluents
- availability of water
- thermal discharge

RESOURCES USED:

(Per 10¹² Btu equivalent electric power generated)

FUEL
natural gas 2.87 x 10⁶ cu.ft.
heat content 1,034 Btu/cu.ft.

Gas Analysis (By volume)

H₂ 11.8
CH₄ 14.8
C₂H₆ 3.1
H₂ 1.0
CO₂ 0.1
O₂ 0.01
S (as H₂S)

WATER (Requirements for pollution control devices)

condensation 0.6
combustion modifications
central waste treatment plant

evaporative cooling 2.5
towers

noise control <0.1

LAND

fixed area Acres⁽³⁾
plant area 4
evaporative cooling towers 0.1-1.4

WATER

once-through evaporative cooling towers 36,000
2,000
800
Dollars(1978⁽³⁾)

COSTS

construction \$3,350,000
labor 420,000
materials 4,410,000
equipment 2,530,000
other construction 35,000
land & land rights 255,000
general plant 111,000,000
total
operation and maintenance \$183,000
labor 64,300
materials 71,500
equipment 72,500
utilities
annual operating cost \$395,300

ESTIMATES AND PRODUCTS:

(Per 10¹² Btu equivalent electric power generated)

AIR POLLUTANTS^(a)

TSP 71.8 - 21.52
SO₂ 0.861
NO_x 1000
HC(as CH₄) 1.43
CO 24.4
gases & mists -
CO₂ -

WATER POLLUTANTS^(a)

alkalinity 26.0
acidity 22.4
BOD 0.396
COD 33.4
TSS 69.1
TDS 64.4
ammonia 0.0740
nitrate 0.394
phosphorus 0.0229
sulfate 278
chloride 20.7
aluminum 9.87
chromium 0.0316
copper 0.0440
iron 0.662
magnesium 6.08
nickel 4.37
sine 0.460
sodium 83.1
surfactants 135
oil & grease 0.00208

TRACE TOXIC ELEMENTS^(f)

arsenic 0.000482
barium 0.00
beryllium 0.00
cadmium 0.00
chlorine 0.000347
chromium 0.00644
cyanogen 0.00
lead 0.0000124
mercury 0.00
manganese 0.000347
toluene 0.00104

Tons

Gross MSPE
71.8 - 21.52 143
1,176 294
294

Revised MSPE

1,176(2)
294

Open cycle Gross Tons

26.0 34.4

Closed cycle Gross Tons

0 0

5.16 37.5

69.1 69.1

341 341

0.0740 0.0740

0.394 0.394

0.0229 0.0229

263 263

47.9 47.9

1.13 1.13

0.0316 0.0316

0.0440 0.0440

0.662 0.662

69.7 69.7

4.37 4.37

0.405 0.405

83.1 83.1

135 135

0.00208 0.00208

Gross Tons

0.000482

0.00

0.00

0.00

0.00

0.000347

0.00644

0.00

0.0000124

0.00

0.000347

0.00104

Note: Please refer to the qualification statements at the beginning of this section on Natural Gas.

Gas-Fired Steam Electric Power Plant (Concluded)

ENERGY SYSTEM:

RESOURCES USED:
(Per 10¹² Btu equivalent electric power generated)

pollution abatement units:	
capital costs	
central treatment plant	127,000
area runoff treatment	18,000
condenser cooling water treatment	8,500
(ec)	
cooling tower bleeddown treatment	4,000
cooling system	
once-through (ec)	391,000
evaporative cooling towers	
mechanical draft	755,000
(ec)	
natural draft	1,190,000
operation and maintenance	
central treatment plant	18,300
area runoff treatment	700
condenser cooling water treatment	1,000
(ec)	
cooling tower bleeddown treatment	1,000
cooling system	
once-through (ec)	1,000
evaporative cooling towers	
mechanical draft	4,000
(ec)	
natural draft	2,000

PERSONNEL (4)

	Months/Year			
	First Year	Second Year	Third Year	Fourth Year
construction				
mechanical technical	1.5	3.9	5.1	2.8
mechanical non-technical	0.6	2.4	2.3	1.8
manual	9	3.3	43.8	25.1
construction manpower total	2.1	11.8	49.3	28.3

Months/Year

operation & maintenance	
mechanical technical	1.9
mechanical non-technical	2.0
manual	4.3
operation and maintenance manpower total	8.2

OCCUPATIONAL SAFETY (7)

	Months/Year
deaths	0.00175
injuries	0.187
man-days lost	6.94

RESIDUALS AND PRODUCTS:
(Per 10¹² Btu equivalent electric power generation)

SOLID WASTE

HEAT
stack loss
cooling water loss
+ miscellaneous
station losses

negligible

Btu
0.41 x 10¹²
1.53 x 10¹²

ENERGY PRODUCT

electricity

KW-hrs.
2.93 x 10⁶

- (1) Data applicable to new equipment items, not retrofit cases.
(2) Ceiling 1176 tons/10¹² Btu; requires 90% reduction, requirement waived if SO₂ emission is less than 294 tons/10¹² Btu.
(3) Values are annualized per trillion Btu.

- SOURCES: (a) EPA, Development Document for Proposed Effluent Limitations Guidelines and New Source Performance Standards for the Steam Electric Power Generation Point Source Category, March 1974 and October 1974.
(b) EPA, Technical Report for Revision of Steam Electric Effluent Limitations Guidelines, September 1978.
(c) Zahnstrom, Water Pollution Control for the Steam Electric Power Industry, Vol. 1, 1975.
(d) Sachtel Corporation, Energy Supply Planning Model, 1978.
(e) EPA, Compilation of Air Pollutant Emission Factors, 1977.
(f) NRC, Toxic Pollutant Coefficients for Energy Supply and Conversion, 1977.
(g) University of Oklahoma, Energy Alternatives: A Cooperative Analysis, 1975.
(h) EPA, Compilation of Air Pollutant Emission Factors, 3rd Edition, Supplement 1 to 9, July 1979.

Note: Please refer to the qualification statements at the beginning of this section on Natural Gas.

Underground Natural Gas Storage

ENERGY SYSTEM:

- SIZE**
- 50 wells, 5000 underground acres
 - 60×10^9 SCF annual deliverability
 - 1020 Btus per SCF
 - 61.2×10^{12} Btus annual deliverability
 - 62×10^9 SCF annual recharge
 - 96.77% efficiency^(a)
 - 365 operating days per year
 - 50 year life

DESCRIPTION

- System consists of 50 wells drilled in a depleted gas field. The system is charged annually in the summer and gas is withdrawn in the winter. Working capacity (annual deliverability) is 60×10^9 SCF and 2×10^6 SCF is used as fuel or lost per year. Additional facilities include compressors, metering facilities, scrubbing and dehydration equipment, and 30 miles of 30 inch connecting pipeline.

COMPONENTS

- Depleted underground gas reservoir
- Wells
- Metering facilities
- Gas processing facilities
- 30 inch diameter pipeline

ENVIRONMENTAL CONCERNS

- NO_x emissions from the compressor stations
- Land disturbance during construction
- Aquifer contamination from defective gas well casings

RESOURCES USED: (Per 10^{12} Btus Produced)

ENERGY	
Field use in compressors	.024 $\times 10^{12}$ Btus
lost	.009 $\times 10^{12}$ Btus
LAND	
Acres	
Surface land occupied	0.327
Underground lease	81.700

WATER

Water used for drinking, sanitary use and potential firefighting on site.

Negligible

MATERIALS

Concrete (includes cement)	Tons
Bentonite (in drilling mud)	31,314
Barite (in drilling mud)	5,719
Steel	3,268
Copper	442,569
Aluminum	1,383
Manganese	0.477
Chromium	3,323
Nickel	0.841
Cast iron	0.071
	6,049

COST

	Thousand Dollars (1978)
Construction-Total	1532.00
Labor	597.00
materials	420.00
equipment	391.00
other construction costs	144.00
Operation and Maintenance-Total	15.25
Labor	1.03
materials	0.83
equipment	3.48
other construction costs	9.90

PERSONNEL

Construction (3-Years)	Man Years
non-manual technical	Year 1 Year 2 Year 3
non-manual non-technical	0.515 0.686 0.515
manual	0.114 0.229 0.229
total	1.307 5.536 5.229
Operation and Maintenance	
non-manual technical	0.01157
non-manual non-technical	0.00845
manual	0.02337

RESIDUALS AND PRODUCTS: (Per 10^{12} Btus Produced)

AIR POLLUTANTS^(b)

Particulates	Tons
SO _x	N/A
NO _x	0.1889
HC	136.98
CO	9.447
	3.915

WATER POLLUTANTS

Construction activities may temporarily increase stream sediment loadings. Potential exists for contamination of local aquifers through defective gas well casings.

SOLID WASTE

It is assumed that new wells will be drilled for gas injection and withdrawal. Negligible amounts of solid waste will be produced.

NOISE

Noise during operation would be restricted to compressor stations. Would probably be less than 60 dBA at property boundary.

ENERGY PRODUCT

960,392 $\times 10^6$ SCF natural gas
(1×10^{12} Btus)

Note: Please refer to the qualification statements at the beginning of this section on Natural Gas.

(a) Assumes 62×10^9 SCF into facility per year and 60×10^9 SCF delivered from storage.

(b) Assumes 66,000 HP of compression in use continually. In actual fact, compressor requirements will vary depending on seasonal load and specific characteristics of the system.

SOURCES: Bechtel Corporation, 1978. Energy Supply Planning Model. San Francisco, California.

Federal Power Commission, 1977. Final Environmental Impact Statement for the TAPCO Project. Tennessee Pipeline Company, et al.

Docket No. CP 77-100 et al. Washington, D.C.

Katz, D.L., D. Cornell, R. Kobayashi, F.M. Portmann, J.A. Vary, J.R. Elmhurst, and C.F. Weisberg. Handbook of Natural Gas Engineering. McGraw-Hill, New York.

U.S. Environmental Protection Agency, 1977. Compilation of Air Pollutant Emission Factors. Office of Air and Waste Management, Research Triangle Park, North Carolina.

Natural Gas Transmission Pipeline

ENERGY SYSTEM:

- SIZE:**
- 30 inch outside diameter pipeline
 - 600 mile length
 - 600 MM f per day capacity, 88% load factor^(a)
 - 0.53856 x 10¹² Btus per day input
 - 94.904% efficiency
 - 100% availability
 - 0.52189 x 10¹² Btus per day output (88% load factor)
 - 190,488 x 10¹² Btus per year output (88% load factor)
 - 20 year economic life

DESCRIPTION:

- A 600 mile underground steel pipeline constructed of 30" O.D. x 0.625" API 5LX60 pipe and operating at 1200 psig maximum allowable pressure. Natural gas is driven by six centrifugal compressors located at 100 mile intervals. The compressors are driven by gas turbines fueled by the natural gas in the pipeline. A metering station is located at each end of the pipeline.

COMPONENTS:

- Underground steel pipeline
- Compressor stations
- Metering stations

ENVIRONMENTAL CONCERNS:

- NO emissions from the compressor stations
- Land disturbance during construction, particularly to streams and rivers

RESOURCES USED:

(Per 10¹² Btus Produced)

FUEL

natural gas 1.0117 x 10⁹ SCF Input
energy content 1020 Btus_per SCF
fuel gas consumed 3.13 x 10⁹ SCF
(0.03133 x 10¹² Btus)

COMPOSITION (Percent)^(d)

	On-Shore	Off Shore	Louisiana Gulf
methane	71.51	96.65	
ethane	7.00	2.05	
propane	4.40	0.47	
butanes	0.99	0.17	
pentanes	0.02	0.05	
hexanes and higher	0	0.31	
nitrogen	15.5	0	
carbon dioxide	0	0.30	
helium	0.58	0	

MATERIAL

steel 1643.25 tons^(c)
(82.16 tons)

LAND

total land disturbed 43.35 acres (2.167 acres)^(c)
permanent land affected 19.56 acres (0.978 acres)

WATER

temporary Use (hydrostatic testing) 0.5589 x 10⁶ gallons^(c)
well capacity at compressor stations (2.79 x 10⁶ gallons)^(g)
0.331 x 10⁶ gallons

LABOR

construction 83.00 man-months
(4.15 man-months)^(c)

operation

0.21 man-years

COSTS

construction \$1,468 million
(\$73.6 thousand)^(c)

RESIDUALS AND PRODUCTS:

(Per 10¹² Btus Produced)

AIR POLLUTANTS

	Tons ^(e)
particulates	NA
NO _x	4.001
CO	1.518
HC	0.2759
SO _x	0.0055

WATER POLLUTANTS

Construction activities, particularly stream crossings, may temporarily increase stream sediment loadings. Normal operation should not affect water quality.

SOLID WASTE

None

NOISE^(f)

Noise during construction of pipeline and compressor stations could result in sound levels of 90 dBA along edge of right of-way. Instantaneous sound levels of 121 dBA could occur during blasting. Noise during operation would be restricted to compressor stations and would be less than 60 dBA at boundary of property.

ABSTRACTS

Aesthetic quality of landscape, particularly in forested areas, will be altered for the life time of the pipeline.

ENERGY PRODUCT

980,392 x 10⁹ SCF natural gas (1 x 10¹² Btus)

- SOURCES:**
- Federal Power Commission, 1973. National Gas Survey, Vol. III, Transmission. Washington, D.C.
 - Characteristics of the natural gas transmission line are based on a Federal Power Commission import application filing by Tennessee Atlantic Pipeline, FPC Docket No. CP77-100 at al.
 - For a one time commitment of resources, the first numbers represent resources used per annual 10¹² Btus, the values in parenthesis indicate the resources used per 10¹² Btus over the 20 year economic life of the project.
 - Sepulcher, C.G. ed. 1964. Gas Engineers Handbook. Industrial Press, New York.
 - Derived from: U.S. Environmental Protection Agency, 1977. Compilation of Air Pollutant Emission Factors. Office of Air and Waste Management, Research Triangle Park, North Carolina.
 - Federal Power Commission, 1977. Final Environmental Impact Statement for the TAPCO Project. Tennessee Atlantic Pipeline Company, at al. Docket No. CP77-100 at al. Washington, D.C.
 - Well capacity represents the normal total capacity of 20 gallons per minute of the wells, at six compressor stations per 10¹² Btus produced. It is not anticipated that any of these wells would operate at capacity for any length of time.

Note: Please refer to the qualification statements at the beginning of this section on Natural Gas.

ENERGY SYSTEM:

- SIZE**
- 125,000 cubic meter capacity (2.6 BCF) tanker
 - 95.3% availability (348 days)
 - 95.8% efficiency (percent of cargo delivered)
 - 12 roundtrips per year (26 days at sea, 3 days in port)
 - 20 knots service speed, 12,000 nautical mile roundtrip
 - 350 metric tons (827.4 cubic meters) "heel" on return voyage^(a)
 - 31.053×10^{12} Btus delivered per year (1020 Btus per cubic foot gas)
 - 25 year service life^(c)

DESCRIPTION

- A 63,460 deadweight ton tanker with five 25,000 cubic meter insulated cryogenic tanks to hold liquefied methane at -260°F.
- Ship length, 289; beam, 41; design draft, 11; maximum shaft horsepower, 40,000;
- 35 crew accommodations; service space, 20 knots. Ship is double hulled with one propeller.

COMPONENTS

- LNG Tanker^(b)

ENVIRONMENTAL CONCERNS

- Potential risk to crew and coastal populations in event of pool fire or vapor ignitions following LNG spill. Risk ranges from negligible to equivalent to natural events such as hurricanes, typhoons, and lightning.

RESOURCES USED:

(Per 10^{12} Btu Produced)

FUEL (1020 Btus per SCF natural gas) ^(d)	
Boil-off burned to power tanker	29.3×10^9 Btu
Fuel oil to power tanker	27.6×10^9 Btu
Boil-off vented	7.72×10^9 Btu

LAND^(b)

None

WATER

Seawater to cool shipboard
LNG boil-off condensers

Gallons

 984.25×10^6

MATERIALS

	Tons
steel	1092.313 (43.7)(c)
copper	8.602 (0.344)(c)
aluminum	3.375 (0.143)(c)
manganese	9.274 (0.371)(c)
chromium	34.004 (1.360)(c)
nickel	16.864 (0.673)(c)
cast iron	3.691 (0.148)(c)

COST

	Thousand Dollars (1978)
Construction total	6440 (257.6)(c)
labor	3220 (128.8)(c)
equipment and materials	3220 (128.8)(c)
Operation total	879
labor	22.54
maintenance, provisions	856.60

PERSONNEL

	Man Years
Construction (3 years)	77.287 (3.092)(c)
Operations	1.127

RESIDUALS AND PRODUCTS

(Per 10^{12} Btu Produced)

Air Pollutants	Tons
Particulates	2.458
SO _x	7.424
NO _x	5.842
HC	0.524
CO	0.405
Methane vented	166.52

WATER POLLUTANTS

Water stream from shipboard
LNG boil-off condensers would be
5.9°F above ambient at sea and
7.4° above ambient in port.

SOLID WASTE

None anticipated

NOISE

NA

ENERGY PRODUCT - Liquid Natural Gas

1×10^{12} Btus
 19.569×10^3 metric tons LNG
 980.392×10^6 SCF natural gas

(a) The "heel" on a ballasted ship is a residual volume retained in the LNG tanks to keep them cold.

(b) Analysis is restricted to the ship component only. Shore-based support facilities must be considered separately.

(c) For a one-time commitment of resources, the first number represents resources used per annual 10^{12} Btus delivered by the tanker, the value in parenthesis indicates the resources used per 10^{12} Btus delivered over the entire 25 year service life of the tanker.

(d) Fuel use calculations assume the ship burns 2/3 boil-off gas and 1/3 oil while loaded, 1/3 boil-off gas and 2/3 oil while ballasted, and all boil-off while in port. Calculations also assume engine run at .75 load factor while steaming and .15 load factor in port, in both cases at 33 percent efficiency.

SOURCES: Federal Power Commission, 1977. TAPCO Project, Final Environmental Impact Statement, Docket No. CP 77-100 et al. Washington, D.C.
Bliss, C., P. Clifford, G. Goldgraben, E. Graf-Webster, K. Krickenberg, E. Maher, and E. Zimmermann. 1976. Accidents and Unscheduled Events Associated with Non-Nuclear Energy Resources and Technology. The HITE Corporation, NT6-68, McLean, Virginia.
Agouris, P., 1975. A Case History: Economics of an LNG Project. Ocean Industry, March 1975.
U.S. Department of Energy, 1978. Western LNG Project, Final Environmental Impact Statement, Docket No. CP75-140, Federal Energy Regulatory Commission, Washington, D.C.
McGowan, John, 1979. Office of Shipbuilding Cost, U.S. Maritime Administration. Personal Communication.
Callagher, J.M. et al., 1978. Resource Requirements, Impacts, and Potential Constraints Associated with Various Energy Futures. Bechtel Corporation, Inc., August 1978, San Francisco, California.

Note: Please refer to the qualification statements at the beginning of this section on Natural Gas.

Synthetic Fuels

Solvent Refined Coal II

ENERGY SYSTEM:

SIZE Fuel Input (a)
 • 3155 TPD raw coal
 • 8.09 x 10¹¹ Btu/day (HW)

Product Output (a)
 • 43,241 BPD SRC fuel oil
 • 14,601 BPD fuel oil
 • 4,054 BPD naphtha
 • 467 TPD sulfur
 • 70 TPD ammonia
 • 37 TPD phenols
 • 5.18 x 10¹¹ Btu/day total product output
 • 170 x 10¹² Btu annual total product output

Plant Characteristics
 • 64% plant efficiency (HW)
 • 30 years plant life (a)
 • 90% on stream factor (a)

DESCRIPTION:

• Pulverized, dried coal is slurried with a process derived oil. After the addition of hydrogen, the pressurized coal/oil/hydrogen mixture is preheated and then pumped into the reactor (2000 psi, 850°F) for the actual liquefaction reaction. The reactor effluent is let down separating the gaseous products from the slurry. The product gases are cleaned, recycled (hydrogen) or burned (fuel gas) for in-plant power/heat. Some liquid product is recycled, the rest is separated from the heavy bottom slurry by distillation. The heavy bottom is pacified for hydrogen production.

COMMENTS:

• coal pulverizers/dryers
 • hydrogen plant (Tennessee partial oxidation unit)
 • preheaters
 • tubular plug flow reactor
 • product recovery units (flash separators, atmospheric and vacuum distillation units)
 • gas processing units (scrubbers, sulfur recovery, etc.)

ENVIRONMENTAL CONCERNS

• air emissions
 • water pollution from runoff and leachates
 • solid waste
 • occupational hazards and health effects
 • noise pollution
 • odor

The data presented are based on a conceptual design of a commercial facility. The data will be updated when more current data become available. The data should not be used directly for comparison with other coal liquefaction processes.

(1) Representative values selected for analysis purposes.

SOURCES: (a) Hittman Associates, Inc., *Standard of Practice Manual for Solvent Refined Coal Liquefaction Process*, 1978.

(b) Hittman Associates, Inc., *Environmental Assessment of Coal Liquefaction*, 1978.

(c) TSM, *Characterizations and Data in the Area of Coal Mass Environmental Data Book*, Volume IV, 1978.

(d) Flank and Fryer, *Boiler Fuel and Building Blocks*, 1978.

RESOURCES USED:

(Per 10¹² Btu Produced)

FUEL Tons
 raw bituminous coal 62,880

COAL (RAW) PROXIMATE % (by weight)

ANALYSIS (a)
 moisture 2.7
 ash 7.13
 volatiles 36.47
 fixed carbon 51.70

sulfur content (a) 3.38
 heating value (HHV) (a) 12,921 Btu/lb (HW)

LAND (c) Acres
 plant facilities 2.1
 solid waste disposal NA.

CONSUMPTIVE WATER USE

Acres-Ft.
 potable water 1.46
 boiler feed water make-up 19.51
 process water 30.22
 waste water 5.67
 utility water 2.32
 cooling water 128.14
 Total 185.32
 recovered water 37.31
 Total make-up water (river) 148.01

COSTS Dollars - 1978
 construction (a) 9,020,000
 operation 1,920,000

PERSONNEL (a) Workers
 construction NA
 operation and maintenance 5.7

RESIDUALS AND PRODUCTS:

(Per 10¹² Btu Produced)

AIR POLLUTANTS (c) Tons
 particulates 1.6
 SO₂ 22.0
 NO_x 30.1
 hydrocarbons 3.9
 CO 1.6
 arsenic 1.8 x 10⁻⁴
 cadmium 1.7 x 10⁻⁴
 mercury 2.9 x 10⁻³
 zinc 1.3 x 10⁻³
 chromium 2.7 x 10⁻³
 nickel 5.9 x 10⁻⁴
 lead 6.2 x 10⁻⁴
 polynuclear organic material 1.5 x 10⁻⁹

WATER POLLUTANTS
 no direct discharge to any watercourse

SOLID WASTE (a) Tons
 dry ton equivalent 6,348

ENERGY PRODUCT (1) 149,234
 syn crude (SRC II)
 (energy content = 6.7 x 10⁸ Btu/bbl)

ENERGY SYSTEM:

SITE:

Fuel Input:

- 27,836 TPD ROM coal
- 15,000 TPD dry coal
- 66×10^{12} (.637 $\times 10^{12}$) Btu/day HHV (LHV)

Product/Output:

- 36,152 TPD syn crude
- 24,686 TPD naphtha
- 348×10^{12} Btu/day liquid product yield (LHV)
- 1,192 TPD sulfur
- 234.6 TPD ammonia
- 13.7 TPD phenols
- 1.56 $\times 10^{10}$ Btu/day (1,940 Mwh/day) electric power (solid)
- 127.4 $\times 10^{12}$ Btu total annual product output

Plant Characteristics:

- 60.0% (61.7%) plant efficiency LHV(HHV)
- 20 years plant life
- 91.3% (8,000 hr/year) on stream factor
- 405 acres plant size
- 1,150 M\$ (1975) total capital costs

DESCRIPTION:

- Dried, pulverized coal is slurried with recycled oil, mixed with hydrogen, preheated and pumped into an ebulliating bed reactor with a cobalt-molybdenum catalyst. Gases, vapors and liquid (slurry) are separated by condensation (flash), distillation (atmospheric and vacuum) and hydrocyclone units. The concentrated bottom slurry can be used for hydrogen production.

COMPONENTS:

- Coal preparation (4 Lonscha mills for crushing, drying classifying)
- Hydrogen Plant (Tennessee partial oxidation unit)
- Preheaters
- Ebulliating Bed Reactors
- Product Recovery Units (separators, atmospheric and vacuum distillation units)
- Gas Processing Units (scrubbing, sulfur recovery, etc)

ENVIRONMENTAL CONCERNS:

- air emissions
- solid waste
- water pollution from runoff and leaching
- occupational hazards and health effects
- noise
- odor

RESOURCES USED:
(Per 10^{12} Btu Produced based on LHV)

FUEL:

coal: bituminous ROM
energy content

COAL ANALYSIS: ROM
(Illinois No. 6)

moisture 10.0
carbon 63.48
hydrogen 4.81
nitrogen .86
sulfur 4.43
oxygen 7.28
ash 9.12

LAND (3)

plant facility 3.1
solid waste disposal 0
(returned to mine)

CONDENSATIVE WATER USE:

percolate water 1.46
boiler feed water make up 19.31
process water 30.22
waste water 3.67
utility water 2.32
cooling water 126.14
Total 185.32
recovered water 17.31
Total make up water (river) 168.01

COSTS:

construction (4)

operation

PERSONNEL (4)

construction (4)
operation and maintenance

72,831 tons
11,900 Btu/lb HHV
11,443 Btu/lb LHV

% (by weight)

10.0
63.48
4.81
.86
4.43
7.28
9.12

Acres

3.1
0

Acres-Ft.

1.46
19.31
30.22
3.67
2.32
126.14
185.32
17.31
168.01

Dollars - 1975

5,020,000

1,920,000

Manpower

NA
5.7

RESIDUALS AND PRODUCTS:
(Per 10^{12} Btu Produced)

AIR POLLUTANTS:

particulates(5)
SO₂(mm.)
NO_x(%,5)
hydrocarbons (5)
CO

Tons

4.4
72
40.9
0.4
NA

WATER POLLUTANTS:

no direct discharge
into any water source

Tons

0

SOLID WASTE:

dry ton equivalent

7,354

PRODUCTS:

syn crude
naphtha
ammonia
sulfur
phenols
electric power

Tons

95,338 barrels
64,578 barrels
614 tons
3,119 tons
62 tons
5,120 MWh

- (1) The data presented are based on a conceptual design of a commercial facility. The data will be updated when more current data become available. The data should not be used directly for comparison with other coal liquefaction processes.
- (2) Including power generation.
- (3) This represents load committed to use over the lifetime of the plant, divided by the annual output of the plant, expressed in trillion Btu.
- (4) This represents total cost or manpower, divided by the annual output of the plant, expressed in trillion Btu.
- (5) These data not available from Fluor, for comparison data from TMS, Characterizations and Data in the Area of Coal Based Environmental Data Book, Volume IV, 1978 are added.

SOURCE: Fluor Engineers and Constructors, Inc., 1976. H-Coal, Commercial Evaluation. FE-2002-12.

Lurgi Process - Lignite Coal

ENERGY SYSTEM:

- SIZE**
- 275 x 10⁶ BCU output (stream day)
 - plant fuel efficiency = 87.3%
 - 912 plants availability
 - North Dakota lignite, 7,200 Btu/lb
 - 37,372 tons coal feed to gasifier
 - 997 Btu/scf energy content of SNG
 - 0.274 x 10¹² Btu/day output
 - 91.03 x 10¹² Btu/year output
 - 135 MW auxiliary power required
 - 30 year plant life

DESCRIPTION

- The Lurgi gasifier is used to produce substitute natural gas from lignite coal. The Lurgi process converts coal particles into a gas in a fixed-bed gasifier. The raw gas is processed and purified to yield an output product gas that is equivalent to natural gas in heating value. The Lurgi plant is capable of using any coal as its input raw material. (Pines are not currently gasified).

COMPONENTS

- coal crusher
- Lurgi gasifier
- shift converter
- Breunford gas clean-up
- tubowall methanator
- oxygen plant
- limestone scrubber
- mineral pulveriser
- stack
- waste water treatment
- landfill

ENVIRONMENTAL CONCERNS

- solid waste disposal
- criteria pollutants from boiler
- large water demand

*535 acres required for the 91.03 x 10¹² Btu/year plant. 5.9 acres are required for a 10¹² Btu plant (535 ÷ 91.03 = 5.9).
 *12,904 MGD are required for the 91.03 x 10¹² Btu/year plant, 192.3 acre-feet per 10¹² Btu.

(1) Consumed by plant to generate steam.

SOURCE: U.S. Department of the Interior, Final Environmental Impact Statement for the ANG Coal Gasification Company (ANOGCC) North Dakota Project, 1978.

RESOURCES USED:

(Per 10¹² Btu Produced)

FUEL	
North Dakota lignite	99,533 tons
energy content	7,320 Btu/lb
COAL ANALYSIS (NOW)	% (by weight)
water	35.98
volatile material	27.21
fixed carbon	29.39
ash	7.42
sulfur	1.26

LAND

Acres
 plant site (gasification)
 disposal (mine mouth)

WATER

Acres-Ft.
 consecutive (gasification only)

POWER

utility 300 MW

COSTS

Dollars
 construction
 coal crusher
 Lurgi gasifier
 oxygen plant
 limestone scrubber
 other equipment
 operation & maintenance

PERSONNEL**

Manhours
 construction (9 years)
 operation (30 years)

RESIDUALS AND PRODUCTS:

(Per 10¹² Btu Produced)

AIR POLLUTANTS	
particulates	gasifier
SO ₂	and
NO _x	auxiliaries
hydrocarbons	NA
CO	NA

WASTE WATER
 surface disposal
 deep well disposal

SOLID WASTE

ash (gasifier)
 ash (auxiliary)

BY-PRODUCTS (1)

tar
 tar oil
 naphtha
 phenol
 sulfur

ENERGY PRODUCE

high Btu gas
 (997 Btu/cubic foot)

Tons
30.2
264.3
641.9
NA
NA

Barrels
0
8,000

Tons
6,435

Barrels
16,712
6,150
3,440
3,106
3,835

Cubic Feet
1.00 x 10 ⁹ scf

Lurgi Process - Western Subbituminous Coal

ENERGY SYSTEM:

- SIZE:**
- 288×10^6 Btu/day output
 - 0.275×10^6 Btu/day output
 - 934 Btu/lb heat content
 - 4,992 T/day coal feed rate to auxiliaries
 - 24,266 T/day coal feed rate to gasifiers
 - 8,120 Btu/lb western subbituminous coal
 - plant synthetic gas efficiency = 56.5%
 - 90% plant availability
 - 90.25×10^{12} Btu/year
 - 30 year plant life

DESCRIPTION

- The Lurgi gasifier is used to produce substitute natural gas from bituminous coal. The Lurgi process converts coal particles into a gas in a fixed-bed gasifier. The raw gas is processed and purified to yield an output product gas that is equivalent to natural gas in heating value. The Lurgi plant is capable of using any coal as its input raw material. (Planes are not currently gasified).

COMPONENTS

- coal crusher
- Lurgi coal gasifier
- shift converter
- Stratford gas clean-up
- tailmill scrubber
- oxygen plant
- on-site utilities plant
- limestone scrubber
- mineral pulveriser
- landfill
- waste water treatment
- stack

ENVIRONMENTAL CONCERNS

- solid waste disposal
- criteria pollutants from boiler
- large water demand

RESOURCES USED:

(Per 10^{12} Btu Produced)

FUEL
Western Subbituminous coal
gasifier feed
auxiliaries feed
energy content

COAL ANALYSIS
% (by weight)
fixed carbon
volatile material
sulfur
H₂O
ash

LAND
plant site (permanent)
disposal (mine mouth)

WATER
consumptive

COSTS
construction
coal crusher
Lurgi gasifiers
oxygen plant
limestone scrubber
other equipment
operation & maintenance

PERSONNEL
construction (3 years)
operation (30 years)

RESIDUALS AND PRODUCTS:

(Per 10^{12} Btu Produced)

AIR POLLUTANTS
particulates
SO₂
NO_x
hydrocarbons
CO
CO₂

WASTE WATER:
surface disposal
mine burial

SOLID WASTE
ash

ENERGY PRODUCTS
high Btu gas
(954 Btu/cf)

BY-PRODUCTS
tar
tar oil
ammonia
phenol
sulfur
naphtha

Tons
NA
26.2
26.8
NA
NA
44,916

Barrels
0
6,349

Tons
20,090

Cubic Feet
1.047 x 10¹²

Tons
3,876
2,120
4,669
495
681
873

Acres

10.64

0

Acres-Ft.

105.6

Dollars (1976)

NA

NA

NA

NA

NA

NA

Workers/Year

20.1

10.8

**940 acres are required for the 90.25×10^{12} Btu/year plant. 10.64 acres are required for a 10^{12} Btu plant ($940 \div 90.25 = 10.64$).
**9,482 acre-feet/year are required for the 90.25×10^{12} Btu/year plant. 105.6 acre-feet/year are required for a 10^{12} plant.
($9,482 \div 90.25 = 105.6$).

SOURCE: U.S. Department of the Interior, Final Environmental Statement for the El Paso Coal Gasification Project, San Juan County, New Mexico, 1977.

In-Situ Coal Gasification

ENERGY SYSTEM:

- SIZE** • 250 x 10⁶ scf of RNG equivalent per day
- 126 Btu/scf heat content(1)
 - 250 x 10¹² Btu/day fuel gas output
 - operates 328.5 days per year
 - 90% plant availability
 - overall energy efficiency 51%
 - plant life 30 years

DESCRIPTION

- In-situ processing scope consist of pregasification, followed by gasification and production. Pregasification prepares the coal bed by linking definable pellets in the coal seams such as the inlet and outlet bore holes. The implaced fracture providing the link between inlet and outlet of the bore increases the permeability of the coal bed. This fracture may be accomplished by hydraulic fracturing or explosives. Gasification introduces air into the coal seam which upon contact with the coal produces hydrogen, carbon monoxide, carbon dioxide, water vapor and methane. The product gases are brought to the surface, cleaned and distributed.

COMPONENTS

- drilling equipment
- compressor
- explosives
- gas cleaning and heat recovery equipment

ENVIRONMENTAL CONCERNS

- fugitive air emissions
- water pollution
- subsidence
- noise pollution

RESOURCES USED:

(Per 10¹² Btu of Fuel Gas Produced)

FUEL	
coal (dry)	99,200 tons
ENERGY	Btu
diesel fuel for air compression and mobile equipment	0.33 x 10 ¹²
utilities	0.015 x 10 ¹²

COAL

subbituminous coal (Hanna field)
Btu (dry) 10,285 Btu/lb

Proximate Analysis

% (by weight)	
fixed carbon	43
volatile matter	40
moisture	7
ash	10
sulfur	1

LAND

Acres	
plant facilities	0.24
subsidence (area affected)	1.54

WATER

(2) Acres-Ft. 108

total requirements

costs

construction NA

operation & maintenance NA

PERSONNEL

construction Workers

operation & maintenance NA

RESIDUALS AND PRODUCTS:

(Per 10¹² Btu of Fuel Gas Produced)

AIR POLLUTANTS (3)

	Tons
particulates	14
SO ₂	NA
NO _x	NA
hydrocarbons	160
CO	75

WATER POLLUTANTS

There is zero process discharge. Possibility of underground pollution due to leachates

BY-PRODUCT

sulfur	993 tons(4)
liquid hydrocarbons (tons)	0.05 x 10 ¹² Btu
sensible heat	0.15 x 10 ¹² Btu

ENERGY PRODUCT

Low Btu gas	7.94 x 10 ⁹ scf
HV	126 Btu/scf(1)

Composition

% (by weight)	
H ₂	16.0
CO	6.3
H ₂	55.2
CO ₂	19.2
CH ₄	3.9
Other	1.4

(1) Subsequent tests have reported product gas heating values of 175 Btu/scf.

(2) This value represents total water requirements and does not consider water already present in coal seam.

(3) Estimated fugitive emissions from vehicular traffic and high pressure equipment.

(4) Assuming 100% sulfur recovery.

(5) Represents total land affected, divided by the annual energy output measured in trillion Btu. For example, 20 acres ÷ 82.125 = 0.24 acres/10¹² Btu.

SOURCE: The Environmental Protection Agency, In-Situ Gasification: Status of Technology Environmental Impact, EPA-600/7-77043, 1977.

Surface Oil Shale Mining

ENERGY STRIDE:

- SIZE** • 73,700 tons of raw shale per day
 • 0.413×10^{-12} Btu/day
 • 2,900 Btu/pound of raw shale
 • 30 gallons/ton shale oil content
 • mine operates 328.5 days/year
 • 26.2×10^9 tons of shale mined/year
 • total annual output is 136.67×10^{12} Btu
 • mine life is 30 years

DESCRIPTION

- In surface mining, the overburden is removed exposing the underlying shale. Shale is mined using the bench technique. Shale is fractured through drilling and blasting and transported by trucks to primary crushing site.

COMPONENTS

- drilling equipment
- excavation equipment (cranes)
- crushers
- trucks

ENVIRONMENTAL CONCERNS

- air quality deterioration
- noise
- water requirement
- contamination of underground water
- supplies with saline mine water

RESOURCES USED: (Per 10^{12} Btu Produced)

ITEM	Tons
raw mined shale	178,430
ENERGY	NA
electricity for operating drilling equipment and trucks	NA

COMPOSITION

% (by weight)	
organic material	17.1
water	1.4
inorganic material	81.5

LAND

Acres	
mine development	0.5
disposal of permanent overburden	7.4
storage of spent shale	1.1
disposal of spent shale	1.1

WATER

Acres-Foot	
mining and crushing	2.8 (2.2 - 3.3)

COSTS

Dollars (1978)	
CONSTRUCTION (2)	
manpower	226,033
materials	28,809
equipment	329,049
other cost	16,792
total	600,683
operation & maintenance	NA

PERSONNEL

Workers	
construction	NA
operation & maintenance	NA

RESIDUALS AND PRODUCTS: (Per 10^{12} Btu Produced)

AIR POLLUTANTS	Tons
particulates	21.79
SO ₂	0.21
NO _x	2.95
hydrocarbons	3.44
CO	1.80

WATER POLLUTANTS

probability of saline contamination of underground water by mine water

SOLID WASTE

negligible (see Processing)

ENERGY PRODUCT

Tons	
mined shale rock	178,430

- (1) This represents land committed to use over the lifetime of the plant, divided by the annual output of the plant, expressed in trillion Btu.
 (2) This represents total cost of constructing the plant, divided by the annual output of the plant, expressed in trillion Btu.

SOURCES: Environmental Protection Agency, *Monitoring Environmental Impacts of the Coal and Oil Shale Industries*, 600/7-77-015, February 1977.
 Cameron Engineers Incorporated, *Synthetic Fuels Handbook*, 1975.
 Department of Energy, *Draft Environmental Impact Statement for the (Updated) Prototype Oil Shale Leasing Program*, 1979.
 University of Oklahoma, *Energy Alternatives: A Comparative Analysis*, 1975.
 Bechtel Corporation, *Energy Supply Planning Model*, 1978.

Underground Oil Shale Mining

ENERGY SYSTEM:

- SIZE** = 73,700 tons of raw shale per day
- 0.413×10^{12} Btu/day
 - 2,800 Btu/pound of raw shale
 - 30 gallons/ton shale oil content
 - mine operates 378.5 days/year
 - 24.2×10^6 tons of shale mined/year
 - total annual output is 125.67×10^{12} Btu
 - mine life is 30 years

DESCRIPTION

- Underground mining uses room and pillar technique. The oil shale deposit is entered through a tunnel dug into the side of a valley where an outcrop appears. Pillars are left in place to provide roof support at appropriate intervals. Extraction is also accomplished by drilling and blasting. The broken shale is transported to portable crusher for primary crushing.

COMPONENTS

- drilling equipment
- excavation equipment (cranes)
- crushers
- trucks

ENVIRONMENTAL CONCERNS

- air quality deterioration
- noise
- water requirement
- contamination of underground water supplies with saline mine water

RESOURCES USED:

(Per 10^{12} Btu Produced)

FUEL	Tons
raw mined shale	178,150
ENERGY	NA
electricity for operating drilling equipment and trucks	
COMPOSITION	% (by weight)
organic material	17.1
water	1.4
inorganic material	81.5
LAND (1)	Acres
mine development	0.13
crushing	2.93
WATER	Acres-Foot
mining and crushing	2.8 (2.3 - 3.3)
COSTS	Dollars (1978)
construction (2)	
manpower	164,224
materials	43,249
equipment	254,842
other cost	82,341
total	544,655
operation & maintenance	NA
PERSONNEL	Workers
construction	484
operation & maintenance	NA

RESIDUALS AND PRODUCTS:

(Per 10^{12} Btu Produced)

AIR POLLUTANTS	Tons
particulates	4.44
SO ₂	0.012
NO _x	0.17
hydrocarbons	0.019
CO	0.10

WATER POLLUTANTS

probability of saline contamination of underground water with mine water

SOLID WASTE

negligible (see Processing)

ENERGY PRODUCT

mined shale rock Tons 178,150

(1) This represents land committed to use over the lifetime of the plant, divided by the annual output of the plant, expressed in trillion Btu.

(2) This represents total cost of constructing the plant, divided by the annual output of the plant, expressed in trillion Btu.

SOURCES: Environmental Protection Agency, Monitoring Environmental Impacts of the Coal and Oil Shale Industries, 600/7-77-015, February, 1977.
 Conserve Engineers Incorporated, SPURTRIC Shale Mine, 1975.
 Department of Energy, Draft Environmental Impact Statement for the (updated) Prototype Oil Shale Leasing Program, 1979.
 University of Oklahoma, Energy Alternatives: A Comparative Analysis, 1975.
 Bechtel Corporation, Energy Supply Planning Model, 1978.

TOSCO II Shale Retorting

ENERGY SYSTEM:

- SIZE** 50,000 bbl/day of crude shale oil
- 16.43 x 10³ barrels of oil/year
 - 28 x 10³ bbl/day
 - 5.6 x 10³ gal/barrel
 - operates 328.5 days/year
 - total annual output 53.27 x 10³ bbl
 - plant life 30 years
 - plant efficiency (thermal) 67%

DESCRIPTION

- Heated ceramic balls are fed into a horizontal retorting cylindrical reactor and mixed with crushed shale (1/2 inch diameter). Pyrolysis occurs at 900°F. Shale oil steam and gases are emitted from one end of the reactor and are collected and fed into a fractionator for product recovery. The ceramic balls are recycled to a vertical ball heater where reheating for further use occurs.

COMPONENTS

- horizontal cylindrical reactor
- fractionator and column
- naphtha hydrofiner
- gas oil hydrofiner
- hydrogen plant
- by-product recovery

ENVIRONMENTAL CONCERNS

- air quality deterioration
- health effects due to hydrocarbons
- modifications to biological environment
- deterioration of water quality due to leachates and runoff
- solid waste disposal
- socio-economic problems due to high influx of personnel in previously sparsely populated areas

RESOURCES USED:

(Per 10¹² Btu Produced)

FUEL (b)	
raw shale	230,000 tons
oil content	35 gallons/ton
COMPOSITION (a)	
%	
oil	11.8
water	1.4
spent shale	84.9
gas	2.0

LAND (1)	
retorting, upgrading and effluent facilities	Acres
expansion, water containment and greenbelt	3.42

WATER (b)	
Acres-Feet	
cooling towers	15.8
waste heat boilers	16.5
water treatment plant	0.4
processed shale	21.3
dust control on shale ash	3.9
sealwater evaporator	7.9
dust scrubbers	10.4
irrigation	1.1
fire and drinking	2.4
total	77.7

COSTS (2)	
Dollars (1978)	
construction	1,840,000
manpower	871,000
materials	1,635,000
equipment	137,000
other cost	4,303,000
total	NA
operation & maintenance	NA

PERSONNEL	
Workers	
construction	2.1
operation & maintenance	11.3

RESIDUALS AND PRODUCTS:

(Per 10¹² Btu Produced)

AIR POLLUTANTS (b)	
Tons	
particulates	19.6
SO ₂	11.4
NO _x	63.3
hydrocarbons	11.2
CO	2.7

WATER POLLUTANTS	
assume zero direct discharge to any water-course	

SOLID WASTE (b)	
Tons	
spent shale	190,000

ENERGY PRODUCT	
Barrels	
refined shale oil	172,400 barrels
heat content	5.6 x 10 ³ Btu/barrel

- (1) Land use value represents land committed to use for the facility, divided by annual production, measured in trillion Btu.
- (2) Costs are total costs for plant construction, divided by annual output, measured in trillion Btu.

- SOURCES:** (a) Environmental Protection Agency, *Monitoring Environmental Impacts of the Coal and Oil Shale Industries*, 600/7-77-015, February 1977.
- (b) University of Denver, *Denver Research Institute, An Engineering Analysis Report on the TOSCO II Shale Process*, March 1977.
- (c) University of Oklahoma, *Energy Alternatives: A Comparative Analysis*, 1975.
- (d) Bechtel Corporation, *Energy Supply Planning Model*, 1978.
- (e) Cameron Engineers Incorporated, *Synthetic Fuels Handbook*, 1975.

Modified In-Situ Shale Retorting

ENERGY SYSTEM:

- SIZE**
- 34,200 tons of raw shale mined/day
 - 101,600 tons of raw shale retorted in-situ/day^(c)
 - shale oil content 25 gallons/ton^(d)
 - 50,000 bbl/day
 - 29 x 10¹² Btu/day
 - 95.3 x 10¹² Btu/year
 - operates 328.5 days/year
 - plant life 30 years
 - thermal efficiency 61% overall^(d)

DESCRIPTION

- in modified in-situ approximately 15-20% of the deposit is mined using conventional mining techniques in the ground and fractured using either chemical, hydraulic, or electric means. Prior to fracturing of the deposit, parallel wells (productions and injection) are drilled on two opposing sides of the deposit. A retorting fluid (hot steam or gas) is injected within the formation. After ignition, retorting takes place and the oil mist, gas and steam produced are forced to the surface through the production wells. Liquid gathered at the base of the combustion zone is later pumped out. The produce are refined using techniques similar to surface refining.

COMPONENTS

- underground retort created from blasting procedure
- fractionator and boiler
- naphtha hydrofiner
- gas oil hydrofiner
- hydrogen plant
- by-product

ENVIRONMENTAL CONCERNS

- air quality deterioration
- health effects due to hydrocarbons
- modifications to biological environment
- deterioration of water quality due to leachates and runoff
- solid waste disposal
- socio-economic problems due to high influx of personnel in previously sparsely populated areas

*Approximately one barrel of water/barrel of oil is produced during retorting by the release of interstitial water and the combustion of hydrocarbons.

- SOURCES:**
- (a) Commerce Engineers, Incorporated, Synthetic Fuels Handbook, 1975.
 - (b) BEES Data Group, Environmental Characterizations for Energy Technologies and End Uses, Revision 1, 1978.
 - (c) Department of Energy, Draft Environmental Impact Statement for the (Updated) Prototype Oil Shale Leasing Program, 1979.
 - (d) Environmental Protection Agency, A Preliminary Assessment of the Environmental Impacts from Oil Shale Development, 600/7-77-060, July 1977.
 - (e) Ashland Oil, Inc., Lessor & Operator's Oil Shale - Inc., Modifications to Detailed Development Plan, Oil Shale Tract C-2a, February, 1977.

RESOURCES USED:

(Per 10¹² Btu Produced)

FUEL (c,d)	
mined shale	117,900 tons
unmined shale	355,900 tons
oil content	25 gallons/ton

COMPOSITION (a)

S (By weight)	
organic material	NA
water	NA
inorganic material	NA
spent shale	NA

LAND (c)

LAND	
permanent disposal	207-310/Year
surface facilities	345
active well area	867/Year

WATER (c)

WATER (c)	
retorting and upgrading	Acres-Ft.
power generation	(22.2)*
evaporation	24.4
steam injection	0.9
miscellaneous	28.9
total	4.4
	36.4

COSTS (b)

COSTS (b)	
construction	Dollars (1978)
operation & maintenance	11,400,000
	NA

PERSONNEL (b)

PERSONNEL (b)	
construction	Workers
operation & maintenance	30.4
	NA

RESIDUALS AND PRODUCTS:

(Per 10¹² Btu Produced)

AIR POLLUTANTS (d,e)		Tons
particulates		35.6
SO ₂		4.21
NO _x		33.7
hydrocarbons		0.51
CO		10.0

WATER POLLUTANTS

There is assumed a zero direct discharge of effluent into any water course.

SOLID WASTE (d)

SOLID WASTE (d)		Tons
spent shale		99,000

ENERGY PRODUCT

ENERGY PRODUCT		Barrels
refined shale oil		172,400

In-Situ Shale Retorting

ENERGY SYSTEM:

- SIZE** • 132,100 tons of raw shale/day (inground)
 • 30 galling/ton shale oil content
 • 29×10^{12} Btu/day
 • 50,000 Btu/day
 • 16.43×10^6 barrels of oil/year
 • operation 338.5 days/year
 • total annual output 95.12×10^{12} Btu
 • thermal efficiency 55%

DESCRIPTION

- In-situ processing retorts the shale in the ground. This method fractures the shale using either chemical, hydraulic, or electrical means. Prior to fracturing of the deposit, parallel wells (production and injection) are drilled on two opposing sides of the deposit. A retorting fluid (hot steam or gas) is injected within the formation. After ignition, retorting takes place and the oil mist, gas, and steam produced are forced to the surface through the production wells. Liquid gathered at the base of the combustion zone is later pumped out. The products are refined using techniques similar to surface refining.

COMPONENTS

- underground retort created from blasting procedure
 • fracometer and coher
 • naphtha hydrofiner
 • gas oil hydrofiner
 • hydrogen plant
 • by-product recovery

ENVIRONMENTAL CONCERNS

- air quality deterioration
 • health effects due to hydrocarbons
 • modifications to biological environment
 • deterioration of water quality due to leachates and runoff
 • solid waste disposal
 • socioeconomic problems due to high influx of personnel in previously sparsely populated areas

RESOURCES USED: (Per 10^{12} Btu Produced)

FUEL	
retorted shale	455,500 tons
oil content	30 gallons/ton
COMPOSITION (b)	% (by weight)
organic material	NA
water	NA
inorganic material	NA
spent shale	NA
LAND (f)	Acres
surface facilities, permanent	345
active well area, temporary	862
WATER (f)	Acres-ft.
retorting & upgrading	(22.2)
on-site power generation	24.4
steam injection	28.9
miscellaneous	4.4
total	75.5
COSTS (e)	Dollars (1978)
construction	1,895,000
manpower	602,000
materials	2,500,000
equipment	183,000
other cost	5,190,000
total	NA
operation & maintenance	NA
PERSONNEL	Workers
construction	NA
operation & maintenance	NA

RESIDUALS AND PRODUCTS: (Per 10^{12} Btu Produced)

AIR POLLUTANTS (a)	Tons
particulates	51.3
SO ₂	102.7
NO _x	21.4
hydrocarbons	4.4
CO	25.0
WATER POLLUTANTS (a)	
No direct discharge to any water body	
SOLID WASTE (a)	Tons
spent shale	negligible
ENERGY PRODUCT	Barrels
retorted shale oil	172,400

*Approximately one barrel of water/barrel of oil is produced during retorting by the release of interstitial water and the combustion of hydrocarbons.

SOURCES:

- (a) Environmental Protection Agency, Monitoring Environmental Impacts of the Coal and Oil Shale Industries, 600/7-77-015, February, 1977.
 (b) Cameron Engineers, Incorporated, Synthetic Fuels Handbook, 1975.
 (c) Environmental Protection Agency, A Preliminary Assessment of the Environmental Impacts from Oil Shale Development, 600/7-77-049, July 1977.
 (d) University of Oklahoma, Energy Alternatives: A Comparative Analysis, 1975.
 (e) Sachtel Corporation, Energy Supply Planning Model, 1978.
 (f) Department of Energy, Draft Environmental Impact Statement for the (updated) Prototype Oil Shale Leasing Program, 1979.

Solar Energy

Residential/Commercial Hot Water Heating

UNIT ENERGY SYSTEM:

- SIZE** • provides 75% of the load for a 2000 ft² single family house
 • 30 ft² collector array (flat plate)
 • 90 gallon storage tank
 • 7.0 × 10⁶ Btu/yr in Denver

DESCRIPTION

- Solar energy is absorbed onto the collector panels and transferred to storage via a water/glycol working fluid which is pumped through the collector panel and a heat exchanger in a storage tank. Cold water enters the storage tank and is heated by contact with the heat exchanger. Warm water enters a second tank where an auxiliary heat source maintains the water at some desired temperature. Lifetime of the system is assumed to be 20 years.

COMPONENTS

- flat plate solar collectors
- copper piping
- copper heat exchanger
- pump
- hot water tanks (2)
- urethane insulation (2 inches)
- conventional water heater element (electric, natural gas-fired)

ENVIRONMENTAL CONCERNS

- possible accidental spillage or leakage of working fluid
- hazard potential of toxic working fluid
- collector overheating or fire
- fluid disposal

Chemical Oxygen Demand accounting withness disposal of all working fluid in water.

SOURCE: Los Alamos Scientific Laboratory, 1979. *The Characterization and Assessment of Selected Solar Thermal Energy Systems for Residential and Process Heat Applications*, LA-7945-TASE. Los Alamos, New Mexico. Technology Assessment of Solar Energy (TASE) Project, Solar Technology Assessment Program, Technology Assessment Division, OTI, IV, 206.

RESOURCES USED:

(Number of Unit Systems to Yield 10¹² Btu/yr) N = 142,857

TECH

(Per 10¹² Btu Produced)
 solar insulation
 auxiliary power requirements = 7.2 × 10⁶ kWh
 conventional fuel required to cover 25% of the load

MATERIALS

(10³ tons per N units)

steel	26.6
glass	5.8
urethane	5.9
copper	2.1
coolant	5.8

LAND

negligible

WATER

53 acre-ft per 10¹² Btu produced

COSTS

\$1,234 (1977\$) per unit
 \$176.3 × 10⁶ (1977\$) per N units

PERFORMANCE

Data not available

RESIDUALS AND PRODUCTS:

(Per 10¹² Btu Produced)

AIR POLLUTANTS

none

WATER POLLUTANTS

COD = 632 tons

SOLID WASTE

none

WASTEWATER

none

ENERGY PRODUCE

10¹² Btu thermal

Solar Heating and Cooling of Building Systems

5

6

Residential/Commercial Heating—Active System

UNIT ENERGY SYSTEM:

- SIZE** • provides 75% of the load
 • 500 ft² collector (flat plate)
 • 900 gallons storage
 • 47.5×10^6 Btu/yr produced in Denver **

DESCRIPTION

- An array of flat plate collectors absorbs solar thermal energy and transfers it to storage via solution of water and glycol alcohol. The heated water in the tank is pumped through a heat exchanger in the house to provide space heating. Lifetime of the system is assumed to be 20 years.

COMPONENTS

- solar collector panels (double-glassed)
- storage tank
- copper heat exchangers (2)
- pumps (2)
- valves (2)
- vents
- system controls
- urethane insulation

ENVIRONMENTAL CONCERNS

- possible accidental spillage and leakage of working fluid
- hazard potential of toxic working fluid
- collector overheating or fire
- fluid disposal

RESOURCES USED:

(Number of Unit Systems to Yield 10^{12} Btu/yr; $N = 21,013$)

FUEL

(Per 10^{12} Btu Produced)
 solar insulation
 auxiliary power requirement - 10.41×10^6 kWh
 conventional fuel required to cover 25% of the load

MATERIALS

(10³ tons per N units)

steel	40.5
glass	6.4
urethane	3.9
copper	1.7
insulant	8.4

LAND

negligible

WATER

226 acre-ft per 10^{12} Btu produced

COSTS

\$11,823 (1977\$) per unit
 \$248.9 $\times 10^6$ (1977\$) per N units

PERSONNEL

data not available

RESIDUALS AND PRODUCTS:

(Per 10^{12} Btu Produced)

AIR POLLUTANTS

none

WATER POLLUTANTS

CDD* 774 tons

SOLID WASTE

none

WASTEWATER

none

ENERGY PRODUCT

10^{12} Btu thermal

*Chemical Oxygen Demand assuming ultimate disposal of all working fluid in water.

** Based on an assumed 6 month heating season

SOURCE: Los Alamos Scientific Laboratory, 1979. The Characterization and Assessment of Selected Solar Thermal Energy Systems for Residential and Process Heat Applications. LA-7995-TASE, Los Alamos, New Mexico. Technology Assessment of Solar Energy (TASE) Project, Solar Technology Assessment Program, Technology Assessments Division, OTI, KY, DOE.

1. The first part of the document is a list of names and addresses of the members of the committee. The names are listed in alphabetical order, and the addresses are given in full. The list is as follows:

Residential Heating and Cooling—Active System

UNIT ENERGY SYSTEM:

- SIZE** • provides 75% of the heating and cooling load
- 500 ft² collector area (flat plate)
 - 900 gallons storage
 - 71 x 10⁶ Btu/yr in Denver **

DESCRIPTION

- An array of flat plate collectors absorbs solar thermal energy and transfers it to storage via a solution of water and glycol alcohol. The heated water in the tank is pumped through a heat exchanger in the house to provide space heating, or is pumped through an absorption-type refrigerator. Lifetime of the system is assumed to be 20 years.

COMPONENTS

- solar collector panels (double-glazed)
- storage tank
- copper heat exchangers (2)
- one-inch diameter copper piping (100 feet)
- pumps (2)
- valves (2)
- absorption-type refrigerator
- vents
- system controls
- urethane

ENVIRONMENTAL CONCERNS

- possible accidental spillage or leakage of working fluid
- hazard potential of toxic working fluid
- collector overheating or fire
- fluid disposal

RESOURCES USED:

(Number of Unit Systems to Yield 10¹² Btu/yr; N = 14,085)

FUEL

(Per 10¹² Btu Produced)
solar insulation
auxiliary power requirement - 7.1 x 10⁶ kWh
conventional fuel to cover 25% of the load

MATERIALS

(10³ tons per N units)

steel	30.6
glass	5.7
urethane	2.6
copper	1.8
coolant (ethyl glycol)	5.6

LAND

negligible (roof mounted)

WATER

173 acre-ft. per 10¹² Btu produced

COSTS

\$21,458 (1977\$) per unit
\$330.4 x 10⁶ (1977\$) per N units

PERSONNEL

Data not available

RESIDUALS AND PRODUCTS:

(Per 10¹² Btu Produced)

AIR POLLUTANTS

none

WATER POLLUTANTS

COD* 1130 tons

SOLID WASTE

none

WASTEWATER

none

ENERGY PRODUCT

10¹² Btu thermal
(heating and cooling)

*Chemical Oxygen Demand assuming ultimate disposal of all working fluid in water.

** Based on an assumed 8 month operating season

SOURCE: Los Alamos Scientific Laboratory, 1979. The Characterizations and Assessment of Selected Solar Thermal Energy Systems for Residential and Process Heat Applications. LA-7975-TASB. Los Alamos, New Mexico. Technology Assessment of Solar Energy (TASE) Project, Solar Technology Assessment Program, Technology Assessments Division, OTI, ST, DOE.

Residential/Commercial Heating—Passive System

UNIT ENERGY SYSTEM:

- SIZE • provides 75% of the heating load
- 500 ft² concrete wall
 - 47.5 x 10⁶ Btu/yr in Denver*

DESCRIPTION

- During sunlight hours, solar radiation penetrates the covering glass and is absorbed by the concrete wall. The concrete radiates heat, which circulates by natural convection to heat interior living space. At night, an insulating drupe is deployed between the two panes of covering glass to reduce heat loss. Lifetime of the system is assumed to be 20 years.

COMPONENTS

- high density concrete wall (18 inches thick)
- glazing (two 1/8 inch thick sheets)
- insulating drupe

ENVIRONMENTAL CONCERNS

- none

RESOURCES USED:

(Number of Unit Systems to Yield 10¹² Btu/yr; N = 21,053)

FUEL

(Per 10¹² Btu Produced)
solar insolation
no ancillary energy required

MATERIALS

(10¹² tons per N units)

glass	8.4
concrete	1170
insulation	1.0

LAND

negligible

WATER

negligible

COSTS

\$6,400 (1977\$) per unit
\$138.9 x 10⁶ (1977\$) per N units

PERSONNEL

Data not available

RESIDUALS AND PRODUCTS:

(Per 10¹² Btu Produced)

AIR POLLUTANTS

none

WATER POLLUTANTS

none

SOLID WASTE

none

WASTEWATER

none

ENERGY PRODUCT

1012 Btu thermal

* Based on an assumed 6 month heating season

SOURCE: Los Alamos Scientific Laboratory, 1979. The Characterization and Assessment of Selected Solar Thermal Energy Systems for Residential and Process Heat Applications. LA-7995-TASE. Los Alamos, New Mexico. Technology Assessment of Solar Energy (TASE) Project, Solar Technology Assessment Program, Technology Assessments Division, OTI, EV, DOE.

Solar Agricultural and Industrial Process Heat Systems

Low Temperature Solar AIPH

UNIT ENERGY SYSTEM:

SIZE • provides 30-100°C low temperature industrial process heat

- 900 gallon storage tank
- 500 ft² collector area (flat plate)
- 65 x 10³ Btu/yr in Indianapolis

DESCRIPTION

- Solar energy is absorbed onto nonreflective surfaces of collector panels. Thermal energy is transferred from collectors to storage, using a closed water/glycol loop and a copper heat exchanger immersed in the storage tank. Fluid in the storage tank is then pumped through a second heat exchanger to produce low temperature process heat. Lifetime of the system is assumed to be 20 years.

COMPONENTS

- flat plate solar collector
- 900 gallon storage tank
- 2 copper heat exchangers
- 100 ft. of 1 in. diameter copper piping
- 2 pumps
- 2 valves
- expansion tanks
- vents
- system controls

ENVIRONMENTAL CONCERNS

- leakage or spillage of system fluid
- product contamination
- fluid disposal

RESOURCES USED:

(Number of Unit Systems to Yield 10¹² Btu/yr; N = 15,355)

FUEL

(Per 10¹² Btu Produced)
solar insulation
auxiliary energy requirement - data not available

MATERIALS

(10³ tons per N units)

steel	16
glass	1.32
wrothene	1.54
copper	0.66
coolant	4.1

LAND

negligible

WATER

133 acre-ft. per 10¹² Btu produced

COSTS

Data not available

PERSONNEL

Data not available

RESIDUALS AND PRODUCTS:

(Per 10¹² Btu Produced)

AIR POLLUTANTS

none

WATER POLLUTANTS

COD* 645 tons

SOLID WASTE

none

WASTEWATER

data not available

ENERGY PRODUCT

10¹² Btu thermal

*Chemical Oxygen Demand assuming ultimate disposal of all working fluid in water.

SOURCE: Los Alamos Laboratory, 1979. The Characterization and Assessment of Selected Solar Thermal Energy Systems for Residential and Process Heat Applications. LA-7995-TASE. Los Alamos, Mexico. Technology Assessment of Solar Energy (TASE) Project, Solar Technology Assessment Program, Technology Assessment Division, OTT, RV. DOE.

Medium Temperature Solar AIPH

UNIT ENERGY SYSTEM:

- SIZE:**
- provides 140-300°C medium temperature industrial process heat
 - 500 sq ft** concentrating collector area
 - 900 gallon storage tank
 - 102.5 x 10⁶ Btu/yr in Madison, Wisconsin

DESCRIPTION

- Sunlight strikes parabolic reflector surfaces and is reflected/concentrated onto the absorber surface at the vertex. Therminol 66 is pumped through the vertex to transfer heat to storage. Lifetime of the system is assumed to be 20 years.

COMPONENTS

- concentrating collectors tracking-type (compound parabolic)
- timing mechanism
- 900 gallon storage tank
- 2 copper heat exchangers
- 100 ft. of 1-inch diameter copper piping
- 2 pumps
- 2 valves
- expansion tanks
- vents
- system controls

ENVIRONMENTAL CONCERNS

- leakage or spillage of system fluid
- product contamination
- fluid disposal

RESOURCES USED:

(Number of Unit Systems to Yield 10¹² Btu/yr; N = 9,756)

FUEL

(Per 10¹² Btu Produced)
solar insulation
auxiliary energy requirement - data not available

MATERIALS

(10³ tons per N units)

steel	38.5
glass	3.9
aluminum	3.41
urethane	5.92
coolant	(data not available)

LAND

24 acres per N units

WATER

192 acre-ft. per 10¹² Btu produced

COSTS

Data not available

PERSONNEL

Data not available

RESIDUALS AND PRODUCTS:

(Per 10¹² Btu Produced)

AIR POLLUTANTS

none

WATER POLLUTANTS

COD* 674 tons

SOLID WASTE

none

WASTEWATER

none

ENERGY PROPERTIES

1012 Btu thermal

*Chemical Oxygen Demand assuming ultimate disposal of all working fluid in water.

**Collector size is normalized to 500 ft². Depending upon specific application, more than one module may be required; i.e., 1,268 unit systems would be needed to provide 50% of the medium temperature (100-300°C) process heat load for a 200,000 tons/year pulp mill.

SOURCE: Los Alamos Scientific Laboratory, 1979. The Characterization and Assessment of Selected Thermal Energy Systems for Residential and Process Heat Applications. LA-7995-TASE. Los Alamos, New Mexico. Technology Assessment of Solar Energy (TASE) Project, Solar Technology Assessment Program, Technology Assessments Division, OTE, NY, DOE.

Photovoltaic Energy Systems

Residential Photovoltaic System

UNIT ENERGY SYSTEM:

SIZE • supplies power to 1,507 ft² home in Phoenix
 • collector area 904 ft²
 • 16,420 kWh/yr (after losses)

DESCRIPTION

• Sunlight striking the photovoltaic cells induces a dc electrical current which is fed either to battery storage or is converted into alternating current and supplied for immediate use in the home.

COMPONENTS

• array of silicon-based photovoltaic cells
 • battery storage subsystem
 • inverter

ENVIRONMENTAL CONCERNS

• release of toxic gases during system operation or malfunction
 • solid waste disposal
 • inhalation of toxic gases and dusts by PV industry workers

RESOURCES USED:

(Number of Unit Systems to Yield 10¹² Btu/yr; N = 17,849)

FUEL

(Per 10¹² Btu Produced)
 solar insolation
 auxiliary power requirement - data not available

MATERIALS

(Tons per N unit)

plastic	20.02 x 10 ³
silicon	6.16 x 10 ³
aluminum	33.8
silver	27.7
antimony	2.7
tin	1.74 x 10 ³
lead	3.16 x 10 ³
antimony	7.35 x 10 ³
polypropylene	2.55 x 10 ³
sulfuric acid	6.99 x 10 ³
steel	4.43 x 10 ³
copper	1.2 x 10 ³
tin	5.89
porcelain	2.56
varnish	35.1
glass	5.89

LAND

minimal

WATER

258.8 acre ft per 10¹² Btu produced

COSTS

Data not available

PERSONNEL

Data not available

RESIDUALS AND PRODUCTS:

(Per 10¹² Btu Produced)

AIR POLLUTANTS

none

WATER POLLUTANTS

none

SOLID WASTE

none

WASTEWATER

data not available

ENERGY PRODUCT

2.93 x 10⁸ kWh

SOURCE: Los Alamos Scientific Laboratory, 1979. Decentralized Solar Photovoltaic Energy Systems, LA-7846-TASK. Los Alamos, New Mexico. Technology Assessment of Solar Energy (TASE) Project, Solar Technology Assessment Program, Technology Assessments Division, OTI, NV, DOE.

Solar Photovoltaic Power Plant (Central Utility)

ENERGY SYSTEM:

- SIZE**
- factory rated power is 86.3 MW
 - reflectors and Phoenix location lead to 109 MW peak field performance
 - power conditioning efficiency of 92%
 - capacity factor 0.3 due to availability of solar energy
 - availability of 0.9
 - no storage system
 - field consists of 5518 arrays; each producing 48,700 kWh/year
 - field produces 0.843×10^{12} Btu/year

DESCRIPTION

- A flat panel array consisting of single-crystal silicon photovoltaic cells with 16% in-panel efficiency converts solar energy to electricity. The system employs a reflector to increase performance. Power conditioning complement is designed to be capable of delivering peak array power.

COMPONENTS

- solar arrays
- reflecting surfaces
- inverters/converters
- transformers
- medium voltage cabling

ENVIRONMENTAL CONCERNS

- potential for a variety of chemical releases during manufacture of cells
- thermal release and thermal parameter changes over large land areas, possibly producing local weather changes
- glare from solar arrays
- large land area used, creating ecological disruptions and competition with other land uses
- lack of sufficient quantitative information about potential residuals

*Data for other materials not available.

**Costs are for 1985 construction, and assume large decrease from present costs.

SOURCES: The MITRE Corporation, *Systems Descriptions and Engineering Costs for Solar-Related Technologies*, Vol. VIII, June 207.
U.S. Energy Research and Development Administration, *Environmental Development Plan, Photovoltaic Energy Conversion*, 1977.

RESOURCES USED:

(Per 10^{12} Btu Produced)
(Number of Unit Systems to Yield 10^{12} Btu/yr; N=1.19)

FUEL
Incident solar radiation 5.79×10^{12} Btu's

MATERIALS
concrete
silicon
steel

LAND
site
Acres
230

WATER
for cleaning only

COSTS**
Dollars (1976)
construction field or arrays 97,000,000
power conditioning and facility 19,000,000
total 116,000,000
operation and maintenance 1,860,000

PERSONNEL
Months/Year
construction (peak) 900
operation and maintenance 10

RESIDUALS AND PRODUCTS:

(Per 10^{12} Btu Produced)

AIR POLLUTANTS

no normal releases
releases from damaged cells
silicon (relatively inert) negligible

WATER POLLUTANTS

solvents/detergents (released during washing once every 3-5 months)
sodium phosphate 2-3 cu/3 gallons of water

vegetation suppressants
pesticides

HEAT

thermal releases from collectors to atmosphere
reduction in net solar input to land area
changed reflectivity, absorptivity, emissivity of land area
concentrated solar radiation on collectors producing glare
shading of land

ENERGY PRODUCT
electricity

Ex-Btu 2.93 $\times 10^6$

Wind Energy Conversion Systems

Residential/Commercial Wind Energy Conversion System

UNIT ENERGY SYSTEM:

- SITE**
- provides electric power to residences or commercial buildings
 - 15 KW rated capacity*
 - 22% capacity factor
 - 28,908 KWh/yr

DESCRIPTION

- The machine begins producing electricity when wind speed reaches 8 mph. At 26 mph, the system reaches maximum rated output and at 50 mph, the machine stops generating to protect itself from damage. Lifetime of the system is assumed to be 30 years.

COMPONENTS

- 3 bladed rotor (25 ft in diameter)
- self-excited generator
- small tower
- Genial synchronous inverter
- battery storage

ENVIRONMENTAL CONCERNS

- safety hazards associated with mechanical stress
- electromagnetic interference
- noise
- aesthetics

RESOURCES USED:

(Number of Unit Systems to Yield 10¹² Btu/yr) N = 10,136

FUEL

(Per 10¹² Btu Produced)

wind energy

auxiliary power requirement - data not available

MATERIALS

(10³ tons per N units)

steel	67.23
concrete	1.45
copper	104.1

LAND

66.02 acre per N units

WATER

negligible

COSTS

Data not available

PERSONNEL

Data not available

RESIDUALS AND PRODUCTS:

(Per 10¹² Btu Produced)

AIR POLLUTANTS

none

WATER POLLUTANTS

none

SOLID WASTE

none

HAZARDOUS

none

ENERGY PRODUCT

2.93 x 10⁸ KWh

*Low Wind Regime (12-15 MPH at 10 Meters)

SOURCE: Los Alamos Scientific Laboratory, 1979. Technology Assessment of Wind Energy Conversion Systems. LA-9044-TASE. Technology Assessment of Solar Energy (TASE) Project, Solar Technology Assessment Program, Technology Assessment Division, OTT, NV, DOE.

Wind Energy Conversion System—Electric Utility Application

UNIT ENERGY SYSTEM:

- SIZE**
- power to utility grid
 - 1.5 MW rated capacity
 - capacity factor .38, .33, and .22 for high, moderate and low wind regimes
 - annual output depending on wind: ranges 4.99 GWh to 2.89 GWh/yr depending on wind regime.

DESCRIPTION

- Wind energy turns the rotor to produce shaft horsepower. The machine operates at constant speed by varying the pitch of its rotor blades. Lifetime of the system is assumed to be 30 years.

COMPONENTS

- rotor assembly
- tower
- generator
- an energy storage subsystem may also be included
- step-up gears

ENVIRONMENTAL CONCERNS

- safety hazards associated with mechanical stress
- electromagnetic interference
- noise
- aesthetics

RESOURCES USED:

(Number of Unit Systems to Yield 10^{12} Btu/yr; $N = 101$)

FUEL

(Per 10^{12} Btu Produced)

wind energy
auxiliary energy requirement - data not available

MATERIALS

(10^3 tons per N units)

	Low Wind	Med. Wind	High Wind
steel	17.4	9.33	5.44
copper	0.135	0.092	0.079
concrete	55.38	31.3	21.75
fiberglass	1.956	0.942	0.498

LAND

50,5

WATER

negligible

COSTS

Data not available

PERSONNEL

Data not available

RESIDUALS AND PRODUCTS:

(Per 10^{12} Btu Produced)

AIR POLLUTANTS

none

WATER POLLUTANTS

none

SOLID WASTE

none

HAZARDOUS

none

ENERGY PRODUCT

2.93×10^6 kWh

SOURCE: Los Alamos Scientific Laboratory, 1979. Technology Assessment of Wind Energy Conversion Systems. Los Alamos, New Mexico. Technology Assessment of Solar Energy (TASE) Project, Solar Technology Assessment Program, Technology Assessments Division, OTI, EY, DOE.

Solar Thermal Power Systems

Solar Thermal Power Plant (Central Facility)

ENERGY SYSTEM:

- SIZE**
- provides power to utility grid
 - 100 Mw plant
 - net overall plant efficiency 0.234
 - 0.5 capacity factor
 - 0.9 availability
 - 450 Langley's average daily solar radiation
 - 1.50×10^{12} Btu/year energy output
 - 7.45×10^6 sq. ft. total reflector area
 - 1.3 magnification factor
 - 22,500 heliostats, 3 receiver towers 750' high
 - 420 Mwhe storage system with superheated steam transport
 - 30 year plant life

DESCRIPTION

- The central receiver is composed of a field of tracking heliostats (mirrors) which are controlled to reflect incoming direct solar rays to a common absorber (receiver) elevated above the field by a central tower. The energy, in the form of heat, is transferred from the absorber to a working fluid, which in turn is the source of heat for a thermodynamic cycle producing electricity. A storage system retains a portion of the collected energy to be used in cloudy periods, at night, or to delay production of maximum power.

COMPONENTS

- heliostats (mirrors) and tracking control
- tower receiver and heat transport
- thermal storage
- turbogenerator
- cooling tower
- land, buildings, and auxiliary equipment

MAJOR ENVIRONMENTAL PROBLEMS

- handling and disposal of system fluids and wastes (boiler blowdown) leading to water contamination
- heliostat reflection (safety)
- alteration of the microclimate
- large quantities of land used
- ecological impacts of heliostat fields

RESOURCES USED:

(per 10^{12} Btu Produced)
(Number of Unit Systems to Yield 10^{12} Btu/yr; $N = 0.667$)

FUEL	Btu
incident solar radiation	4.27×10^{12}
LAND	Acres
collector field, buildings, waste treatment areas, rail and road connections	670
WATER	Acres-Ft.
consumed by process	19
wakeup water (boiler)	1.4
heliostat washing	
MATERIALS	Tons
aluminum	1,300 - 3,400
concrete	100,000 - 170,000
copper	340 - 670
cerotic (chrome/titanium)	70 - 130
glass	3,300 - 6,700
insulation	1,300 - 2,700
plastic	300 - 1,300
silver	0.7 - 3.3
steel	33,000 - 47,000

WORKING/STORAGE FLUIDS

possible candidates are:

- liquid sodium
- sodium hydride
- hydrocarbon oils
- eutectic salts (sodium or potassium nitrate/nitrites)

COSTS

	Dollars (1976)
construction	39,000,000
collector	4,100,000
receiver	9,100,000
tower	15,900,000
storage	4,000,000
cooling tower	8,700,000
turbogenerator	6,300,000
master control	8,300,000
plant, structures	95,400,000
total	1,000,000 - 1,900,000
operation and maintenance	

PERSONNEL

	Workers/Year
construction (over 2-3 yrs.)	570 - 850
operation and maintenance	
full-time	30
part-time	20

RESIDUALS AND PRODUCTS:

(Per 10^{12} Btu Produced)

AIR POLLUTANTS

no normal releases
possible releases during fire or system rupture of working/storage fluids (dependent on fluid composition)
nitrogen oxides
sodium monoxide/peroxide
sodium hydroxide mist or dusts

WATER POLLUTANTS

no normal releases
accidental or emergency release of system fluids and wastes, as well as periodic system flushing may cause toxic releases, dependent on fluid composition
hydrocarbon oils
corrosion inhibitors
chromate, borate, nitrate, nitrite, sulfates, sulphite, arsenate, and benzoate salts, triazole, silicate, phosphate compounds
pH controllers
bactericides
chlorinated phenols
freeze protectants
glycols
maintenance related releases
herbicides
chemical dust suppressors
boiler blowdown 19 Acres-Ft.

HEAT

concentrated solar radiation producing glare
fire
reduction of net solar input to land
localized changes in thermal parameters - albedo, energy balance, moisture balance, low-level wind flow patterns, air/surface temperatures, shading of land
thermal releases from cooler tower 1.5×10^{12} Btu

ENERGY PRODUCT

electricity 2.95×10^6 Btu-hrs

SOURCES: U.S. Energy Research and Development Administration, Environmental Development Plan, Solar Thermal Power Systems, 1977.
The NITRE Corporation, Systems Description and Engineering Costs for Solar-Related Technologies, Volume V, 1977.
The NITRE Corporation, Annual Environmental Analysis Report, 1977.

Ocean Thermal Energy Conversion

Ocean Thermal Energy Conversion

UNIT ENERGY SYSTEM:

- SIZE** = 400 Mw, 40°F AT
380°F AT (Oulf design point)
- capacity factor = 0.75-0.90
 - efficiency factor: 0.01
 - power loss
 - AC : 0.31/mi + 22 power conditioning loss
 - DC : 0.011/mi + 22 power conditioning loss
 - offshore distance and transmission mode (AC or DC)
 - AC : 3-30 miles
 - DC : 30-200 miles
 - annual production : 8.4×10^{11} - 10.4×10^{12} Btu
 - 30 years plant amortisation life

DESCRIPTION

- The OTEC system uses the ocean temperature differential between the surface and depth up to 1000 meters to drive a simple Rankine cycle and produce electricity. Power is transmitted to shore by either AC or DC cables depending on distance. The data is based on the ship platform/coldwater pipe concept of Lockheed and Westinghouse design titanium shell and tube heat exchangers and 50 Mw power modules from PED-1 studies.
- Assumes ultimate power system based on a 3000 Mw (8 plant) complexes.
- Performance is site-dependent.

COMPONENTS

- platform
- cold water pipe
- mooring system
- riser cable
- undersea cable
- shore station
- tie point
- heat exchangers
- turbine-generators
- sea water pump
- piping and distribution
- ammonia pump
- controls
- auxiliary systems
- biofouling control

MAJOR ENVIRONMENTAL PROBLEMS

- changes in oceanic properties
 - environmental effects of ocean water-mass displacement
 - destruction of marine eco-system by impingement/entrainment of biota
 - local climate alteration
- chemical pollution
 - ecological effects of biocide discharges
 - ecological effects of working fluid leaks
 - marine food chain contamination from metal corrosion
- ecological impacts associated with the operations of a manned platform
 - artificial reef
 - life-support system discharges
- international/institutional aspects of environmental law and agreements
- secondary effects
 - site selection
 - environmental/ecological impacts of OTEC construction and operations
 - worker safety

RESOURCES USED:

(Per 1012 Btu Produced)
(Number of Unit Systems to Yield 10^{12} Btu/yr; $N = 0.119$)

SEAWATER

warm 1.3 - 1.6 x 10^{11} cf/yr
cold 1.3 - 1.6 x 10^{11} cf/yr

WORKING FLUIDS

ammonia
initial inventory 770-950 tons
makeup 10 tons per year

LAND

shore station 20 acres

MATERIALS

	Tons
concrete	45,000-54,000
steel	7,500-9,200
titanium	980-1,210
copper	490-605
lead	190-230
rubberized nylon	600-750

CONST

	Dollars (1976)
construction	230-290
(3 years)	
operation and maintenance	16-20
engineering/technical	Not Available

RESIDUALS AND PRODUCTS:

(Per 1012 Btu Produced)

AIR POLLUTANTS

no releases

CIRCULATED SEAWATER

warm 1.3-1.6 x 10^{11} cf
cold 1.3-1.6 x 10^{11} cf

WATER POLLUTANTS

free chlorine	1,700-2,000 tons
ammonia	negligible
oil and grease	negligible
nutrients	negligible
metals	negligible

ENERGY PRODUCT

electricity 2.93×10^8

SOURCES: N. Abelson, OTEC Power System Performance Model, MITRE Corporation, MIT 7924, August, 1978.
Dory Associates, Critique of OTEC Phase II Commercial Applications Study Cost Estimates.
Dory Associates Technical Report Number 189, May 31, 1978.
General Electric Corporation, Development, Design and Testimony of OTEC Power System Development II, Briefing Document, March 8, 1978.
W.E. Jacobson and R.H. Manley, OTEC Commercialization Analysis, MITRE Corporation, MIT 7963, January, 1979.
Lockheed Missile and Space Company, Interim Design Briefing, PED II, March 7, 1979.
Lockheed Missile and Space Company, OTEC Power System Development, Phase I - Preliminary Design Report, LMSC-DS-50218.
TEW Incorporated, OTEC Power System Development, Phase I, October 1978.
TEW Incorporated, OTEC PED II Utilizing UCC/Linde Enhanced Plate Heat Exchanger, March 8, 1979.
Westinghouse Incorporated, OTEC Power System Development, Phase I, October, 1978.
Personal Communication: Lloyd Lewis, Department of Energy, April, 1979.

Biomass Energy Systems

Low BTU Wood Gasification System (Central Facility)

UNIT ENERGY SYSTEM:

- SIZE**
- provides process heat or feed-stock for methanol production
 - 850 dry-tonne-per-day input capacity
 - 60,000 acres of wooded land needed to support this capacity
 - 40.7×10^{12} Btu/day of 260 Btu/lb³ gas
 - 3.86×10^{12} Btu/yr output

DESCRIPTION

- Logs are reduced to a uniform chip size and fed into an oxygen-blown pyrolytic reactor. Product gas leaves the reactor at about 93-316 degrees C. Composition is approximately: 46% CH₄, 27% H₂, 13% CO, 5% H₂O, 8% CO₂, and 1% N₂. Heating value is about 260 Btu/lb³. Off-gas is scrubbed and precipitated before compression and storage. Lifetime of the system is assumed to be 25 years.

COMPONENTS

- loading platform
- dump hopper vehicle
- log chipper
- parallel conveyors
- surge pile
- front-end loader vehicles
- live storage bin
- reactor vessel
- water scrubber
- electrostatic precipitator
- condenser
- compressor
- gas storage tank
- waste cover treatment unit

ENVIRONMENTAL CONCERNS

- a most significant impacts are associated with the actual harvesting of the wood;
- plant emissions are relatively low.
- depletion of soil fertility and erosion
- potential hazard of water pollutants; i.e., phenols, trace metals and leachates

RESOURCES USED:

(Number of Unit Systems to Yield 10^{12} Btu/yr; $N = 0.259$)

FUEL
(Per 10^{12} Btu Produced)
wood 66×10^3 dry tons (8500 Btu/lb)
heating value
auxiliary energy requirement - 11.2×10^6 kWh

MATERIALS
data incomplete

LAND
2.67 acres per N units

WATER
33.1 acre-feet per 10^{12} Btu produced

COSTS
 $\$14.69 \times 10^6$ (1976) per unit
 $\$3.80 \times 10^6$ (1976) per N units

PERSONNEL
construction 109 man-years per unit
operation and maintenance
Data not available

RESIDUALS AND PRODUCTS:

(Per 10^{12} Btu Produced)

AIR POLLUTANTS	Tons
particulates	0.36
SO ₂	1.05
NO _x	7.9
HCl	1.7
CO	10.8

WATER POLLUTANTS	Tons
suspended solids	940
NO ₃	11.06
Ca	0.01
Cr	0.004
Cu	0.007
Hg	0.0018
Mn	1.8
Ni	0.01
Pb	3.94
Zn	7.96

SOLID RESIDUES
slag/ash - 803 tons

WASTEWATER
data not available

ENERGY PRODUCT
 1×10^{12} Btu low Btu gas

SOURCE: Oak Ridge National Laboratory, 1979. Characterizations of Selected Applications of Biomass Energy Technologies and a Solar District Heating and Cooling System. Technology Assessment of Solar Energy (TASE) Project, Solar Technology Assessment Program, Technology Assessments Division, OTI, KY, DOE.

Low BTU Gas from Pyrolysis of Corn Residues (Central System)

UNIT ENERGY SYSTEM:

- SIZE**
- provides gas for agricultural/ industrial applications
 - 11,800 tons/yr corn residue
 - 64,000 ft³/hr low Btu gas (heating value 150 Btu/ft³)
 - 0.18 tons/hr char (4.5% ash content)
 - 7.6×10^{10} Btu/yr low Btu gas yield
 - 4.1×10^{10} Btu/yr char by-product

DESCRIPTION

- The model corn pyrolysis system is a gasification unit which operates at a temperature of approximately 875°C to produce low to medium Btu gas and charcoal. Three unit operations are required: (1) storage, (2) handling, (3) gasification.

COMPONENTS

- storage facility
- gasifier and controls
- materials handling system

ENVIRONMENTAL CONCERNS

- air emissions from process
- soil nutrient depletion and erosion from residue collection

RESOURCES USED:

(Number of Unit Systems to Yield 10^{12} Btu/yr; N = 13.2)^a

FUEL
 10^{12} Btu Produced
 corn residue - 156,250 tons @ 20% moisture;
 11.6×10^6 Btu/ton heating value
 auxiliary energy requirement
 electricity - 321,000 kWh
 gasoline - 43,421 gallons

MATERIALS

(Per N units)
 data not available

LAND

3.3 acres per N units

WATER

negligible

COSTS

\$160,220 (1978) per unit
 $\$2.11 \times 10^6$ (1978) per N units

PERFORMANCE

construction .466 man-years
 operation and maintenance
 data not available

RESIDUALS AND PRODUCTS:

(Per 10^{12} Btu Produced)

AIR POLLUTANTS	Tons
particulates	36.6
NO _x	32.1
SO ₂	36.6

WATER POLLUTANTS

negligible

SOLID WASTE

solid by-product has market value is not included in pollutant calculations

WASTEWATER

data not available

ENERGY PRODUCTS

Low-Btu gas 10^{12} Btu
 char by-product 0.54×10^{12} Btu

^a = 0.5 if energy value of by-product char is included as yield.

SOURCE: Argonne National Laboratory, 1979. Environmental and Economic Evaluation of Energy Recovery from Agricultural and Forestry Residues. ANL/RES-TH-26. Argonne, Illinois. Technology Assessment of Solar Energy (TASE) Project, Solar Technology Assessment Program, Technology Assessment Division, OTI, EV, DOE.

Low BTU Gas from Pyrolysis of Wheat Residues (Central System)

UNIT ENERGY SYSTEM:

- SIZE**
- provides gas for agricultural/ industrial applications
 - 12,510 tons/yr wheat residue
 - 73,846 ft³/hr gas (heating value 130 Btu/ft³)
 - 0.2 ton/hr char (heating value 12,800 Btu/lb)
 - 7.8 x 10¹² Btu/yr low Btu gas
 - 4.1 x 10¹⁰ Btu/yr char by-product

DESCRIPTION

- The pyrolytic conversion of wheat residue to medium-Btu gas is similar to that described for corn residues, with a corresponding lower heating value than corn-derived gas.

COMPONENTS

- storage facility
- gasifier and controls
- materials handling systems

ENVIRONMENTAL CONCERNS

- air emissions from process
- soil nutrient depletion and erosion from residue collection

RESOURCES USED:

(Number of Unit Systems to Yield 10¹² Btu/yr; N = 13.2)

FUEL

(Per 10¹² Btu Produced)
 wheat residue 164,583 tons
 auxiliary energy requirement
 electricity - 321,000 kWh
 gasoline - 43,421 gal

MATERIALS

(Tons per N units)
 data not available

LAND

3.3 acres per N units

WATER

negligible

COSTS

\$160,220 (1977\$) per unit
 \$2.11 x 10⁶ (1977\$) per N units

PERSONNEL

construction .466 man-years per unit
 operation and maintenance
 data not available

RESIDUALS AND PRODUCTS:

(Per 10¹² Btu Produced)

AIR POLLUTANTS

	Tons
particulates	36.6
NO _x	52.1
hydrogen sulfide	29.6

WATER POLLUTANTS

negligible

SOLID WASTE

solid by-product has market value and does not enter environment as pollutant

WASTEWATER

data not available

ENERGY PRODUCT

10¹² Btu low Btu gas
 0.54 x 10¹² Btu char as by-product

SOURCE: Argonne National Laboratory, 1979. Environmental and Economic Evaluation of Energy Recovery from Agricultural and Forestry Residues. ANL/RES-TN-36. Argonne, Illinois. Technology Assessment of Solar Energy (TASE) Project, Solar Technology Assessment Program, Technology Assessment Division, OTI, ST, DOE.

Low BTU Gas from Pyrolysis of Feed Lot Manure (Central Facility)

UNIT ENERGY SYSTEM:

- SIZE**
- provides gas for agricultural/industrial process applications
 - plant is based 145,000 head of cattle
 - 500 tons/day raw manure
 - day raw manure (92% moisture)
 - 13.7×10^6 ft³/day gas (heating value 300 Btu/ft³)
 - 1.19×10^{12} Btu/yr yield

DESCRIPTION

- The model system consists of 2 fluidized-bed reactors. Six unit operations are required: (1) manure drying, (2) pyrolysis reactor and char condensation, (3) process gas cooling, (4) CO₂ removal, (5) sulfur recovery and (6) condensate treatment.

COMPONENTS

- pyrolysis reactor
- vessels and tanks
- columns
- pumps and blowers
- heat exchangers

ENVIRONMENTAL CONCERNS

- air emissions
- release of water-borne heavy metals

RESOURCES USED:

(Number of Unit Systems to Yield 10^{12} Btu/yr; $N = 0.84$)

FUEL

(Per 10^{12} Btu Produced)
raw manure - 1.83×10^5 tons
auxiliary power requirements
electricity - 558,900 kWh
gasoline - 50,400 gallons

MATERIALS

(Tons per N units)
steel 621
concrete (yards) 214
sand 210
brick 1,034

LAND

2.5 acres per N units

WATER

negligible (perhaps negative)

COSTS

$\$4.325 \times 10^6$ (1972\$) per unit
 $\$3.63 \times 10^6$ (1972\$) per N units

PERSONNEL

construction 46.7 man-years per unit
operation and maintenance data not available

RESIDUALS AND PRODUCTS:

(Per 10^{12} Btu Produced)

AIR POLLUTANTS

	Tons
CO ₂	28.1×10^3
SO ₂	2.75
NO _x	256

WATER POLLUTANTS

	Tons
lead	3.3
copper	1.4
iron	100
nickel	23
manganese	23
cadmium	13
aluminum	93

WASTEWATER

data not available

ENERGY PRODUCT

low to medium-Btu gas 10^{12} Btu

SOURCE: Argonne National Laboratory, 1978. Environmental Residuals and Capital Cost of Energy Recovery from Municipal Sludge and Feedlot Manure. AR/ES-DM-51. Argonne, Illinois. Technology Assessment of Solar Energy (TASE) Project, Solar Technology Assessment Program, Technology Assessment Division, OTI, EV, DOE.

Medium BTU Gas from Anaerobic Digestion of Municipal Sludge (Central Facility)

UNIT ENERGY SYSTEM:

- SIZE**
- provides medium Btu gas for sewage treatment plant
 - input 20,170 lb/hr solids with 75% volatile
 - plant sufficient to support population of about 2 million
 - pumping filtration devices: 96×10^6 Btu/day
 - 5.2×10^{11} Btu/yr

DESCRIPTION

- Effluent from a municipal waste treatment plant proceeds through a two-stage anaerobic digestion process. A methanogenic culture in the second stage digester produces a mixture of methane (CH_4), CO_2 , and traces of other gases including H_2S . The product gas has a heating value of about 600 Btu/ ft^3 .

COMPONENTS

- emissions related to fuel gas combustion; heavy metals contained in effluent
- two-stage anaerobic digesters (5)
- vacuum filtration devices (3)
- 75 horsepower vacuum pumps (3)
- 10 horsepower pumps (5)
- 5 horsepower pumps (5)
- wet well

ENVIRONMENTAL CONCERNS

- heavy metals in effluent
- hydrogen sulfide and ammonia odor

RESOURCES USED:

(Number of Unit Systems to Yield 10^{12} Btu/yr; $N = 1.92$)

FUEL

sludge 87.6×10^3 tons
auxiliary power requirement - data not available

MATERIALS

steel 2.2×10^3 tons/unit systems
concrete 15.6×10^3 yards/unit systems

LAND

9.4 per unit

WATER

none (water recovered from sludge)

COSTS

$\$4.03 \times 10^6$ (1972) per unit
 $\$7.78 \times 10^6$ (1972) per unit

PERSONNEL

construction 99.4 man-years per unit
operational
Data not available

RESIDUALS AND PRODUCTS:

(Per 10^{12} Btu Produced)

AIR POLLUTANTS

	Tons
SO_2	210
NO_x	140
CO_2	42,900

WATER POLLUTANTS

	Tons
BOD	1,400
suspended solids	1,210

SOLID WASTE

heavy metals:	Tons
As	7
Cd	4
Cu	170
Pb	170
Hg	2
Ag	38
Se	4
Zn	424
Mn	34

ENERGY PRODUCT

medium-Btu gas 1×10^{12} Btu

SOURCE: Argonne National Laboratory. Environmental Residuals and Capital Cost of Energy Recovery from Municipal Sludge and Feedlot Manure. ANL/ES-TH-53. Argonne, Illinois. Technology Assessment of Solar Energy (TASE) Project, Solar Technology Assessment Program. Technology Assessments Division, DTI, EV, DOE.

Medium BTU Gas from Anaerobic Digestion of Feedlot Manure (Central Facility)

UNIT ENERGY SYSTEM:

- SIZE**
- provide medium Btu gas for heat or process
 - process daily waste from 25,000 head of cattle
 - 750 tons/day raw manure
 - input capacity: 147,500 lbs/day of volatile solids
 - 1.5×10^{11} Btu/yr net yield

DESCRIPTION

- Raw manure is mixed with water and passed through a two-stage anaerobic digestion process. The second stage culture of methanogenic bacteria converts first-stage effluent to CH_4 (methane), CO_2 , and traces of other gases, including H_2S . The gas is refined in an absorption process to remove ammonia, hydrogen sulfide, and 55% of the CO_2 present. The product gas has an average heating value of 710 Btu/ft³. Effluent from the digester is dewatered and can be used as soil conditioner or as animal feed. Lifetime of the system is assumed to be 20 years.

COMPONENTS

- two-stage digester
- 35 horsepower centrifuge
- 10 horsepower pump
- three-acre algae lagoon
- clarifier vessel
- methanolumine
- purification unit

ENVIRONMENTAL CONCERNS

- emissions of CO_2 , NO_2 , NO
- trace amounts of heavy metals in effluent
- hydrogen sulfide and ammonia odor

RESOURCES USED:

(Number of Unit Systems to Yield 10^{12} Btu/Tri; $N = 6.67$)

FUEL

raw manure = 2.1×10^5 tons/yr
ancillary energy requirement - data not available

MATERIALS

steel (10³ tons per N units) 4,309
concrete (10³ yards) 33.1

LAND

20.0 acres per N units

WATER

minimal

COSTS

11×10^6 (1972\$) per unit
 420×10^6 (1972\$) per N units

PERSONNEL

Data not available

RESIDUALS AND PRODUCTS:

(Per 10^{12} Btu Produced)

AIR POLLUTANTS

Pollutant	Tons
SO_2	2,370
NO_2	90
CO_2	29,400

WATER POLLUTANTS

None

SOLID WASTE

Waste	Tons
combined fly	130,700
aluminum	268
cadmium	0.7
copper	9.5
ferrous metals	609
lead	10
zinc	7.1
manganese	73

ENERGY PRODUCT

medium-Btu gas 1×10^{12} Btu

SOURCES: Argonne National Laboratory, 1978. Environmental Residuals and Capital Cost of Energy Recovery from Municipal Sludge and Feedlot Manure. ANL/RES-78-33. Argonne, Illinois. Technology Assessment of Solar Energy (TASSE) Project, Solar Technology Assessment Program, Technology Assessment Division, OTI, ST, DOE.

Geothermal Energy

Geothermal—Vapor Dominated System

SYSTEM SUMMARY:

SIZE: 110 Mw

- 13% conversion factor
- 73% capacity factor
- produces 2.47 x 10¹² Btu per year
- unit 12 of Pacific Gas and Electric Geysers generating system

DESCRIPTION

- Steam is purchased from the Geysers field and is used to drive a turbine generator with condenser water used for cooling. No abatement procedures are used at the generating plant; however, the steam distribution system includes a centrifugal mist separator. Furthermore, H₂S abatement measures are planned for implementation beginning with unit 13.

COMPONENTS

- production wells
- gathering system
- steam distribution system
- turbine-generator
- condensers
- heat rejection system
- gas ejector system
- electrical system and controls
- waste purification

ENVIRONMENTAL CONCERNS

- hydrogen sulfide (H₂S) is toxic, has odor - but control technologies are available
- high noise levels
- disposal of excess steam
- extensive highly site, reservoir, and time dependent
- conflicts with existing community lifestyles

RESOURCE DATA:

(Per 10¹² Btu Produced)

FUEL	
steam	6.7 x 10 ¹² Btu's
LAND (1)	
permanently undisturbed	31.2 - 62.4 acres
	249.6 - 250.8 acres

WATER

water vapor input	1,560
water vapor discharged	1,640
water rejected to wells	320

COSTS

(2)	Dollars
construction (1978) (1)	11,180,000
operation and maintenance (1978)	175,000
annual cost of steam (1978)	3,807,000-5,272,000

ABATEMENT COSTS (3) (1978)

peroxide system	
capital	401,000-490,000
operation and maintenance	128,000-434,000
steam system	
capital	710,000-1,560,000
operation and maintenance	129,000-211,000
geothermal field construction	NA
geothermal field operation and maintenance	NA

PERSONNEL

construction (non-annual)	Months
generating plant	37-43
wall-field	NA
total	NA
operation and maintenance	NA
generating plant	NA
wall-field	NA
total	4-77

RESIDUALS AND PRODUCTS:

(Per 10¹² Btu Produced)

AIR POLLUTANTS (4)

carbon dioxide	156-15,000
ammonia	16-1,800
methane	13-1,500
hydrogen sulfide	5-1,500
arsenic	NA
boron	NA
mercury	NA
hydrogen	NA
water vapor	NA
nitrogen, oxides	NA

WATER POLLUTANTS (5)

carbonates	81-210
ammonia	42-104
SO ₄	NA
silicate	87-160
sulfur	NA
nitrate	NA
chloride	NA
calcium	NA
magnesium	NA
silicon	NA
boron	44-89
total solids from evaporation	NA
organics and volatile solids	NA
water	NA

RADIATION (4)

AIR

Re-222

41

WATER

waste heat (discharged to air)

5.4 x 10¹²

NOISE

wall drilling	75-80 at 50 feet
rod drilling (60 days/wall)	85-120 at 25 feet
air drilling (30 days/wall)	
wall cleaning; open well (3-4 days)	118 at 50 feet
wall testing; open well (14 days)	118 at 50 feet
rock miller	89 at 50 feet
wall blending (variable)	85-86 at 5 feet
wall blowers (infrequent)	118 at 50 feet
construction of plant	
construction operations (1-2 years)	70-90 at 50 feet
plant operation (20-30 years)	
muffled steam line vent (continuous)	90 at 100 feet
jet gas ejector (continuous)	84-117 at 5-10 feet
steam line separator (continuous)	80 at 25 feet
steam line breaks (brief, infrequent)	100 at 30 feet
cooling tower (continuous)	90-90 at 5-10 feet
turbine generator building (continuous)	70 outside

ENERGY

electricity 2.95 x 10⁸ kWh

(1) Data values represent life-cycle values divided by annual energy output, measured in 10¹² Btu.

(2) Construction and operation and maintenance costs are for the plant only.

(3) Costs projected to achieve 99% H₂S abatement at the Geysers. To be installed on all units beginning with unit 14. Does not include cost of retrofitting.

(4) Site specific for the Geysers field. Assumes no abatement measures.

(5) No treatment involved, reinjected through wells.

(6) Values in parentheses indicate actual emissions from the Geysers field operations as presented in Carstee, 1977.

SOURCES: Personal communication with D. J. Cassetta of Pacific Gas and Electric, Comments of Dr. Lynn Anagnost, Lawrence Livermore Lab, 1978. Donald D. Pope, Geothermal Power Plants of the United States—A Technical Survey of Existing and Planned Installations, Brown University, 1978. The MITRE Corporation, Environmental Research Needs for Geothermal Resources Development, Volume 1, EPA-600/9-77-010, D. Carstee, 1977. U.S. Environmental Protection Agency, Western Energy Resources and the Environment: Geothermal Energy, EPA-600/9-77-010, May 1977.

Geothermal-Flash Injection System

ENERGY SYSTEM:

- SIZE:** (1)
- 30 Mw (net) power output
 - 10.1×10^6 lb/hr brine flow rate (net) to plant at 338°/113 psia
 - 13 production wells
 - 4 reinjection wells
 - 0.48×10^{16} lb/hr brine/cooling water flowrate reinjected at 120°/7/113 psia
 - 10 acres plant site
 - 30 years plant life
 - 75 capacity factor
 - 1.131×10^{12} Btu annual power output
 - 8-11% thermal conversion efficiency for 373°/9 brine(2)

DESCRIPTION

Geothermal brine is drawn through production wells and transported to the power plant. Steam is produced from the brine by reducing the brine pressure below its vapor pressure. This process, known as flashing, is performed twice. The excess brine is reinjected through reinjection wells. The noncondensable gas portion of the steam is treated with an H_2S scrubbing process and is released to the atmosphere (estimated H_2S removal of 99%). Condensate steam is used for cooling with excess condensate employed for continuous blowdown and reinjected with the excess brine.

COMPONENTS

- production wells and islands
- reinjection wells and islands
- distribution system
- steam system
- brine system
- cooling system
- H_2S scrubber

ENVIRONMENTAL CONCERNS

- release of noncondensable gases
- high brine levels
- potential groundwater contamination
- land subsidence
- increased seismic activity
- alteration of runoff patterns
- habitat disruption
- all factors are highly site specific

NOTE: Allowance for contingency is not included in costs.

(a) Data values represent life-cycle values divided by annual energy output, measured in 10^{12} Btu.

(b) Capital costs include installation, personnel, etc.

(c) Without sulfur removal system

(d) Reaeration

(e) Construction related, results of altered runoff patterns.

SOURCES: (1) Bechtel Corporation, *Advanced Design and Economic Considerations for Commercial Power Plants at Heber and Milad California*, 1977.

(2) Kram, R. L., 1977. "Potential Growth of Electric Power Production from Imperial Valley Geothermal Resources." UCR-52152.

(3) Kram, J. R., and R. E. Orphan, ed., *Program Report - FY 1977, Atmosphere and Geophysical Sciences Division Physics Department*, UCR-51664-77, Lawrence Livermore Labs, 1977.

(4) Environmental Protection Agency, *Water Energy Resources and The Environment: Geothermal Energy*, 1977.

RESOURCES USED:

(For 10^{12} Btu Produced)

FUEL
geothermal brine, 338°/9, 113 psia(1) 2.958×10^7 tons

LAND
(a)
wells and islands (2) 3.57 acres
plant site (2) 8.3 acres

CHEMICALS
alkali for scrubber

COSTS (b)(1)
well field(a) Dollars (1976)
surface equipment 5,352,000
wells 7,136,000
engineering services 1,070,000
subtotal 13,558,000
plant construction (a) 3,986,000-9,064,000
turbine-generator 4,505,000
other mechanical 4,112,000
electrical 1,828,000
civil/structural 3,361,000
engineering services 2,426,000-2,681,000
Subtotal 23,318,000-26,851,000
Total(c) 36,876,000-40,409,000
well field operation and maintenance 1,330,000
plant operation and maintenance 464,000-537,000
Total 1,786,000-1,857,000

PERSONNEL Dollars
field construction NA
field operation NA
plant construction NA
plant operation NA

RESIDUALS AND PRODUCTS:

(For 10^{12} Btu Produced)

AIR POLLUTANTS (3)
hydrogen sulfide(c) Tons 19.4
ammonia 98.8
methane 150
carbon dioxide 35,500
arsenic NA
boron NA
mercury 0.1
hydrogen NA
nitrogen, oxides NA
water vapor 4.3×10^6

WATER POLLUTANTS (4)(3)
carbonates NA
ammonia NA
SO₂ NA
sulfate NA
sulfur NA
nitrate NA
chloride NA
calcium NA
magnesium NA
silicon NA
boron NA
dissolved solids NA
water (lower blowdown) 1.74×10^5
total brine 2.53×10^7
total suspended solids (a) NA
nutrients(a) NA

RADIATION

(5)
ALI 7.3
R₁-222 NA
other radionuclides NA

NOTES

(a) well construction
well operation
plant construction
plant operation
high intensity
intermittent
high intensity
high intensity
medium intensity
low intensity

ENERGY PRODUCE

electricity 2.93×10^8

Hydroelectricity

Large Hydroelectric Plant

ENERGY SYSTEM:

- SIZE** • 200 Mw plant
(composed of three 66.7 Mw generators)
• 54% capacity factor
• lifetime 60 years
• an earth filled dam (containing 15 million cubic yards of earth)
• produces 3.349×10^{12} Btu per year
• 82.6% efficiency

DESCRIPTION

- Conventional hydroelectric plants are assumed to be run-of-river plants: a dam is placed across a river, generating base load power more or less continuously throughout the year. The amount of energy produced by this type of plant is dependent on the site's characteristics and the daily, weekly, or seasonal fluctuations of river flow. In 1974 the developed conventional capacity of hydroelectric power was 57,000 Mw. It is projected to increase some 40 percent to 79,300 Mw by 1995.

COMPONENTS

- dam
- spillways
- intakes
- powerhouses
- conduits
- hydraulic structures
- turbines
- electrical equipment

ENVIRONMENTAL CONCERNS

- inundation of existing habitats created by impoundments of water
- formation of a deep pool of water creating physical, chemical, and biological changes to the environment
- creation of biologically impoverished zones caused by the fluctuations of the reservoir's water level
- alterations of downstream habitats
- modification of animal movement patterns
- imposition of additional sources of stress and mortality to fish and wildlife
- conflicts of land and water use
- dam safety and potential effects of dam failure

RESOURCES USED: (Per 10^{12} Btu Produced)

FUEL
kinetic energy of water 1.2×10^{12} Btu

LAND (1)
acres occupied 119.43

MATERIALS
concrete 44,789 Tons
total steel & castings 4,210
copper, brass & bronze 86
aluminum & castings 45
manganese 25
chromium 6
nickel 1
cast iron 138

COSTS
construction (1) Dollars (1978)
manpower 11,499,000
materials 4,140,000
equipment 11,530,000
plant 850,000
land & land rights 7,234,000
other construction 3,890,000
total 31,900,000
operation & maintenance 110,000
manpower 20,000
materials 80,000
equipment 210,000
total

PERSONNEL
construction (4.75 years) 74.75
operation 5.02

RESIDUALS AND PRODUCTS: (Per 10^{12} Btu Produced)

AIR POLLUTANTS
no normal releases

WATER POLLUTANTS

Water quality and quantity may be altered up and down stream with potential changes in dissolved gases, temperature, and water levels.

HEAT
no normal releases

ENERGY PRODUCT
electricity

2.93×10^8 kWh

(1) Data values represent life-cycle values divided by annual energy output, measured in 10^{12} Btu.

SOURCES: Bechtel National Incorporated, *Resource Requirements, Impacts, and Potential Constraints Associated with Various Energy Futures*, 1978.
The MITRE Corporation, *Features of Hydroelectric Facilities and Their Impact on Fish and Wildlife Resources*, 1977.
Federal Power Commission, *Hydroelectric Power Resources of the United States*, 1976.
Greager, W.P. and J.B. Justin, *Hydroelectric Handbook*.

Small Hydroelectric Plant

ENERGY SYSTEM:

- 4 New plant
- .35 capacity factor for new plants and .37 for retrofits.
- lifetive 50 years
- 80% efficiency
- produces $.04 \times 10^{12}$ Btu/year

DESCRIPTION

Small hydroelectric plants have less than, or equal to 15 Mw of capacity, fed by dams with heights no more than 65 feet, and impounding less than 500 acres. It is estimated that by the year 2000, 21360 Mw of low head hydro could be in existence, contributed by three major types of sources: 15% from presently existing plants; 60% from installed power at existing nonhydro dams, and 25% from installed hydro power and new dams.

COMPONENTS

- dam
- penstock
- hydraulic turbine
- generator
- transformer
- other miscellaneous structures & equipment

ENVIRONMENTAL CONCERNS (1)

- effects on aquatic and semiaquatic organisms
- releases of impounded chemicals
- conflicts of land and water use
- dam safety and potential effects of dam failure.

RESOURCES USED:

(Per 10^{12} Btu Produced)

FUEL Acres-Feet
water 1.98×10^7

ENERGY MWh
electricity NA

LAND Acres
acres occupied NA

COSTS	Dollars (1977)	
	Installed Power at Existing Non-hydro Dams	Installed Hydro-power at New Dams
construction(2)	13,350,000	11,300,000
design	19,570,000	20,700,000
structures	21,360,000	90,340,000
dam & spillway equipment	38,180,000	41,420,000
roads, railways, bridges, etc.	270,000	1,800,000
land & land rights (2,140,000)		(21,590,000)
total	92,660,000	186,460,000
operation and maintenance (1972 dollars)	1,430,000	1,350,000

PERSONNEL Workers
construction NA
operation and maintenance NA

RESIDUALS AND PRODUCTS:

(Per 10^{12} Btu Produced)

WATER POLLUTION

Water quality and quantity may be altered up and down stream with potential changes in dissolved gases, temperature, and water levels.

ENERGY PRODUCT kWh
electricity 2.93×10^8

- (1) As compared to other sources of electricity, the environmental effects of low head hydro are minor.
(2) Costs are total costs for plant construction, divided by annual energy output, measured in trillion Btu.

SOURCES: The NITEL Corporation, Small-Scale Hydroelectric Preliminary Program Plan, 1978.
Bureau of Reclamation, U.S. Army Engineers, Identification of Selected Small-Scale Dams Suitable for Hydroelectric Power Development, 1978.
U.S. Department of Energy, Environmental Readiness Document - Small Scale Low Head Hydro, in Press.
Jelen, P.C., Cost and Optimization Engineering, McGraw-Hill, New York, 1970.

Pumped Storage System

ENERGY SYSTEM:

- SIZE** • 1000 Mw pumped storage plant (composed of four 250 Mw pumps and drivers)
- 13% capacity factor
 - lifetime 60 years
 - two earth-filled dams
 - produces 3.89×10^{12} Btu per year
 - 70% efficiency

DESCRIPTION:

- Pumped storage plants can be thought of as large batteries which store energy (in the form of water) during low demand periods and release that energy during periods of peak demand. Excess energy, usually from base load facilities, is used to make the reversible units act as motors, pumping the water to the upper reservoir. These units then become turbine generators for power production when the water is released during periods of high demand. In 1976, the developed pumped storage capacity in the U.S. was 9,700 Mw. It is projected to increase some 285 percent to 37,300 Mw by 1993.

COMPONENTS:

- dam
- spillways
- intakes
- powerhouse
- conduits
- hydraulic structures
- reversible pump turbines
- electrical equipment

ENVIRONMENTAL CONCERNS:

- inundation of existing habitats created by impoundments of water
- formation of a deep pool of water creating physical, chemical, and biological changes to the environment
- creation of a biologically impoverished zone caused by the fluctuations of the reservoir's water level
- alterations of downstream habitats
- modification of animal movement patterns
- imposition of additional sources of stress and mortality to fish and wildlife
- conflicts of land and water use
- dam safety and potential effects of dam failure

(1) Plus replacement of water lost by evaporation and seepage.

(2) Selected materials and equipment items.

(3) Data values represent life-cycle values divided by annual energy output, measured in 10^{12} Btu.

SOURCES: Bechtel National Incorporated, Resource Requirements, Impacts, and Potential Constraints Associated with Various Energy Futures, 1978.
The MITM Corporation, Patterns of Hydroelectric Facilities and Their Impact on Fish and Wildlife Resources, 1977.
U.S. Federal Power Commission, Hydroelectric Power Resources of the United States, 1976.

RESOURCES USED:

(Per 10^{12} Btu Produced)

Item	Unit
FUEL	
off-peak base load electricity	1.53×10^{12}
LAND (1)	Acres
acres occupied	514.13
MATERIALS (2)	Tons
concrete	151,137
total steel & castings	16,310
copper, brass & bronze	191
aluminum & castings	125
manganese	82
chromium	14
nickel	3
cast iron	333

Item	Dollars (1978)
COSTS (3)	
construction	
manpower	26,630,000
materials	15,740,000
equipment	22,440,000
plant	2,040,000
land & land rights	(7,797,000)
other construction	9,340,000
total	76,210,000
operation & maintenance	
manpower	184,000
materials	39,000
equipment	164,000
total	378,000
PERMANENT	Months
construction (4.5 years)	127.14
operation & maintenance	6.49

WASTEWATER / NO PRODUCTS

(per 10^{12} Btu Produced)

AIR POLLUTANTS:

no normal release

WATER POLLUTANTS:

Water quality and quantity may be altered up and down stream with potential changes in dissolved gases, temperature, and water levels.

WAST:

no normal release

ENERGY PROPERTIES:

electricity 2.93×10^8

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I. SUMMARY

This Environmental Characterization Information Report (ECIR) for Coal-Fired Power Plants (Eastern Coal) has been prepared from the latest available environmental and technical information collected from a number of sources. The typical plant chosen for characterization is a 500-MWe nameplate rating pulverized-coal plant with an electrostatic precipitator, wet scrubber, and a wet-mechanical-draft cooling tower. It is a mine-mouth facility, with its own coal preparation plant.

The process, plant operating parameters, resources needed, and the environmental residuals and products associated with the power plant are presented in this section in the summary table (Table 1). Annual resource usage and pollutant discharges are shown in English and metric units, assuming an annual plant capacity factor of 80 percent. While this capacity factor is representative of the reliability of generating units of this size, it does not consider unscheduled shutdowns for repairs of the plant and associated environmental control equipment or factors independent of the plant itself, e.g., reserve requirements.

In addition to annual quantities, the summary table gives quantities in terms of 10^{12} Btu of electric energy produced. These figures are provided to allow comparison between different energy processes and to facilitate application of the information in computer models.

The supporting information and calculation procedures for the data are given in Section II. Twenty-three environmental points of interest are discussed individually, giving a brief description of the pollutants or resources involved, standards to be met, example calculations showing the derivation of quantities, scaling laws and extrapolation methods to adjust to other conditions, and a bibliography of cited references. Specific environmental regulations are discussed in the individual sections. The calculations of allowable emission levels are based on current Federal regulations applicable to new plants. For information on similar sized plants operating under previous Federal regulations, see Appendix A. For information on impending regulations, see Reference 1.

Section III discusses the overall physical requirements of the plant for land and water. A glossary of terms, cost information, and a trace element analysis are included as appendixes to this report. Data pertaining to additional subjects such as construction resources will be covered in a later version of this ECIR.

Reference

1. U.S. Department of Energy, Office of Technology Impacts, Office of Environment, "Environmental Issues Briefing Book for Policy Analysis Division," original issue April 1979 (compiled by the Mitre Corporation).

TABLE 1. SUMMARY SHEET

COAL-FIRED POWER PLANT (EASTERN BITUMINOUS COAL)

ENERGY SYSTEM DESCRIPTION

Mine-Mouth Conventional Steam Electric Power Plant Using Typical Eastern Bituminous Coal; No Cogeneration; Electrostatic Precipitator for Particulate Control; Wet Lime/Limestone Scrubber for SO₂ Control; On-Site Solid Waste Disposal; and On-Site Water Treatment for Recirculation to Minimize Discharge. New Plant Subject to Current Regulations.

PLANT OPERATING PARAMETERS

Power Output to Grid: 500 MWe
Annual Capacity Factor: 80% (assumed)
Overall Plant Efficiency: 35%
Annual Energy Production: 12 x 10¹² Btu
(3.5 x 10⁶ MW-hrs)
Plant Lifetime: 30 yrs

PROCESS FLOW

RESOURCES USED

Code No.	Resource	Quantities Used Annual Usage*		Per 10 ¹² Btu Energy Produced	Remarks
		English Units	Metric Units		
<u>Fuel</u>					
①	Run-of-min Eastern bituminous coal	1.96 x 10 ⁶ tons	1.77 x 10 ⁶ tonne	0.16 x 10 ⁶ tons	High-sulfur coal (3.3% S)
⑧	Coal feed to boiler	1.43 x 10 ⁶ tons	1.3 x 10 ⁶ tonne	0.12 x 10 ⁶ tons	
<u>Water</u>					
②	Coal preparation makeup water	19-45 x 10 ⁶ gal	57-170 x 10 ⁶ l	1.25-3.75 x 10 ⁶ gal	Quality not critical
⑪, ⑬	Power plant makeup water	2.2 x 10 ⁹ gal	8.3 x 10 ⁹ l	0.18 x 10 ⁹ gal	
⑮, ⑰	Environmental cleaning makeup water	3.2 x 10 ⁷ gal	12 x 10 ⁷ l	0.27 x 10 ⁷ gal	
<u>Raw Materials for Processing</u>					
⑳	Limestone to scrubber	146 x 10 ³ tons	132 x 10 ³ tonne	12.2 x 10 ³ tons	
<u>Land</u>					
④	Land for coal preparation solid waste storage (see Section III)	16 acres	6.5 ha	1.3 acres	Sufficient land needed for a 30 yr life
⑳	Land for power plant and environmental solid waste disposal (see Section III)	12.3 acres	5 ha	1.03 acres	
<u>Personnel</u>					
	Power Plant	135 person-yr		11.3 person-yr	
	Preparation Plant	20 person-yr		1.7 person-yr	
<u>Raw Materials for Construction</u>					
<u>Facility Costs</u>					
<u>Control Costs</u>					
} To Be Added					

*Based on the assumed 80% capacity factor

TABLE 1. (Continued)

COAL-FIRED POWER PLANT (EASTERN BITUMINOUS COAL)

ENVIRONMENTAL RESIDUALS & PRODUCTS

Code No.	Residual or Product	Quantities Released		Per 10 ¹² Btu Energy Produced	Regulatory Compliance Levels
		Annual Levels*			
		English Units	Metric Units		
	<u>Air Pollutants</u>				
③, ⑥	Fugitive dust from coal preparation and storage		Not quantifiable		
②	Post-Control Flue Gas Constituents				
	Sulfur Dioxide (SO ₂)	10.2 x 10 ³ tons	9.3 x 10 ³ te	850 tons	0.6 lb/10 ⁶ Btu
	Oxides of Nitrogen (NO _x)	10.2 x 10 ³ tons	9.3 x 10 ³ te	850 tons	0.6 lb/10 ⁶ Btu
	Total Suspended Particulates (TSP)	500 tons	455 te	42 tons	0.03 lb/10 ⁶ Btu
	Nonmethane Hydrocarbons (HC)	220 tons	200 te	18 tons	Not established
	Carbon Monoxide (CO)	720 tons	655 te	60 tons	
	Carbon Dioxide (CO ₂)	3.7 x 10 ⁶ tons	3.4 x 10 ⁶ te	0.3 x 10 ⁶ tons	
	Arsenic (As)	225 lb	102 kg	18.8 lb	
	Beryllium (Be)	9.3 lb	4.2 kg	0.8 lb	
	Cadmium (Cd)	4.1 lb	1.9 kg	0.4 lb	
	Manganese (Mn)	161 lb	74 kg	13.4 lb	
	Lead (Pb)	114 lb	52 kg	9.5 lb	
	Selenium (Se)	56 lb	25 kg	4.7 lb	
	<u>Water Pollutants</u>				
⑨	Airborne water from cooling tower drift and evaporation	2 x 10 ⁹ gal	7.6 x 10 ⁹ l	0.17 x 10 ⁶ gal	
⑤	Surface run-off from coal preparation solid waste storage		Not quantifiable		
⑬	Excess water runoff from treatment/recycling holding ponds				
	Total Suspended Solids (TSS)		30 mg/l**		30 mg/l***
	Oil and Greases		15.2 mg/l		None
	Copper		0.009 mg/l		1 mg/l***
	Iron		0.009 mg/l		1 mg/l***
	Chlorine		3 0.11 mg/l		None
	<u>Solid Waste</u>				
④	Solid wastes from coal preparation (to storage)	0 525 x 10 ⁶ tons	0.48 x 10 ⁶ te	0.04 x 10 ⁶ tons	
⑭	Bottom ash from boiler (dry)	25 x 10 ³ tons	22.8 x 10 ³ te	2.1 x 10 ³ tons	
⑰	Collected flyash (dry) from precipitator	100 x 10 ³ tons	91 x 10 ³ te	8.3 x 10 ³ tons	
⑱	Limestone scrubber sludge (dry)	193 x 10 ³ tons	175 x 10 ³ te	16 x 10 ³ tons	
	<u>Heat</u>				
⑧	Total heat losses to air	34 x 10 ¹² Btu	10 x 10 ⁶ MW-hr	2.8 x 10 ¹² Btu	

Symbols and abbreviations are discussed in the acronyms and abbreviations section.

*Based on the assumed 80% capacity factor.

**Estimated maximum concentrations for a 30-day average for a typical plant.

***Kentucky water quality standards.

OCCUPATIONAL SAFETY AND HEALTH

	Preparation Plant		Power Plant	
	Annual	Per 10 ¹² Btu	Annual	Per 10 ¹² Btu
Deaths	0.0033-0.0053	0.0003-0.0004	0-0.11	0-0.0095
Injuries	1.9-3.1	0.16-0.26	1.9-2.3	0.16-0.19

II. PROCESS DESCRIPTION AND ENVIRONMENTAL POINTS OF INTEREST

To identify current trends in coal-fired power plant design, the features of 43 modern plants were examined.¹ On the basis of the observed trends, and through discussions with power engineers, a typical plant was chosen for characterization. This composite plant is a 500-MWe pulverized-coal plant with an electrostatic precipitator to control particulate emissions; a wet lime/limestone scrubber for flue gas desulfurization; and a wet, mechanical draft cooling tower. The plant was assumed to be a mine-mouth facility with its own coal preparation plant.

The net station heat rate of 9760 Btu/kWh, which corresponds to an overall efficiency of 35 percent, was taken from an actual 500-MWe plant with similar controls and design features.² The coal used in the analysis is an eastern bituminous coal with a heat value of 12,000 Btu/lb, 3.3 percent sulfur, and 8.8 percent ash.³

The use of an eastern high-sulfur coal for electrical generation is shown in Figure 1. Twenty-three environmental points of interest have been identified in Figure 1 and are discussed in the following sections. Items ① through ⑤ deal with coal preparation, ⑥ and ⑦ deal with onsite coal storage, ⑧ through ⑬ deal with the generating plant itself, and ⑭ through ⑳ deal with pollution controls.

Cost information for the plant is given in Appendix B.

References

1. J.J. O'Connor, ed., Power, 1978 Plant Design Issue, Vol. 122, No. 11, November 1978.
2. Final Environmental Impact Statement, Spurlock Station, Unit No. 2 and Associated Transmission, USDA-REA-EIS-76-4F, Chapter 1, November 1976.
3. G.K. Nielsen, ed., 1978 Keystone Coal Industry Coal Manual, Kentucky #11 Coal, McGraw-Hill, New York, New York, 1978.

FIGURE 1.
PROCESS FLOW CHART WITH
ENVIRONMENTAL POINTS OF INTEREST
COAL-FIRED POWER PLANT —
EASTERN BITUMINOUS COAL —
80% CAPACITY FACTOR

① Run-of-Mine Coal to Coal Preparation

The amount of run-of-mine (ROM) coal to the coal preparation plant is 1.96×10^6 tons/yr.

The ROM coal is assumed to be extracted from an underground eastern mine drift mine operating in thin seam (<40 inches thick) bituminous coal).^{1,2} The mined material is assumed to contain rock, slate, and other refuse normally associated with underground mining. The material has moisture, some of which occurs naturally, and some of which is added by in-mine sprays for dust control. The material is carried to the surface preparation plant by conveyor and to the out-of-mine sections, which are enclosed. No Federal regulations apply to the characteristics of the mined material.

To determine the quantity of ROM coal entering the preparation plant, the heat rate, the proposed operating power level of the power plant, and the operating characteristics of the coal preparation plant must be known. The typical power plant design used in this ECIR has a heat rate of 9760 Btu/kWh, and the generating plant operating level is 500 MWe. The coal preparation plant can operate effectively between 20 percent and 30 percent rejection rates.² It is assumed that the rejection rate for this coal in this preparation plant has been found empirically to be 27 percent. This typical operating point was established through review of similar circuit operation and accumulated operating experience.³

The calculations are as follows:

$$\begin{aligned}\text{Required heat input} &= (\text{Station power output})(\text{net station heat rate})(\text{hr/day}) \\ &= (5.0 \times 10^5 \text{ kWh/hr})(9760 \text{ Btu/kWh})(24 \text{ hr/day}) \\ &= 117 \times 10^9 \text{ Btu/day}\end{aligned}$$

Using the coal cleaning plant operating point of 27 percent rejection, the cleaned coal will have an energy content of 12,000 Btu/lb. Therefore,

$$\begin{aligned}\text{ROM coal into the preparation plant} &= \frac{(\text{heat input})}{(\text{coal heat content})(1 - \text{rejection rate})} \\ &= \frac{(117 \times 10^9 \text{ Btu/day})}{(12.0 \times 10^3 \text{ Btu/lb})(2 \times 10^3 \text{ lb/ton})(1 - 0.27)} \\ &= 6.7 \times 10^3 \text{ tons/day}\end{aligned}$$

On a yearly basis,

$$\begin{aligned}\text{ROM coal into the preparation plant} &= \\ (6.7 \times 10^3 \text{ tons/day})(0.8 \text{ capacity factor})(365 \text{ days/yr}) \\ &= 1.96 \times 10^6 \text{ tons/yr}\end{aligned}$$

The amount of ROM coal input for any preparation plant and power plant combination can be calculated for any coal by applying the plant's known heat rate, the typical preparation plant rejection rate, and cleaned coal Btu content to the above formulas.

References

1. G.K. Nielsen, ed., 1978 Keystone Coal Industry Coal Manual, Kentucky #11 Coal, McGraw-Hill, New York, New York, 1978, p. 505 and pp. 920-921.
2. S.M. Cassidy, "Elements of Practical Coal Mining," Society of Mining Engineers, New York, New York, 1973, pp. 346-356.
3. P.J. Phillips and P.P. DeRienzo, "Assessing the Economics of Steam," Coal Preparation, Coal Mining and Processing, September 1977, p. 75.

② Makeup Water to Coal Preparation

The required makeup water for the coal preparation plant ranges from 15×10^6 gal/yr to 45×10^6 gal/yr.

The coal preparation plant assumed in this system design consists of crushing, washing, and sizing/screening operations, all of which are conducted in the presence of moisture (wet circuit). The system is designed to dewater the coal prior to delivery using screen and hydrocyclone separators and to recirculate the water in the system through a thickener to remove suspended solids. Some water will leave the plant as surface moisture on the clean coal and the rejected refuse material and must be made up by moisture arriving on the surface of the input ROM coal or from a makeup water source. The quality of this makeup water is not critical, and it may come from any of a number of sources such as wells, streams, or mine dewatering.

Because the surface moisture on the input coal is not highly controlled, the makeup requirement will be variable. In general, however, some makeup water will be required.¹

While the makeup water requirement will vary with the preparation plant capacity, it is not necessarily directly scalable and will depend on empirical experience with a particular preparation circuit and ROM coal.² However, this value will not generally exceed 20 gal/ton of ROM coal processed, which equals 40×10^6 gal/yr at an 80-percent capacity factor.

References

1. S.M. Cassidy, "Elements of Practical Coal Mining," Society of Mining Engineers, New York, New York, 1973, p. 435.
2. Personal Communication, Mr. William Ostarello, Roberts and Schaefer Co. Engineers and Contractors, Chicago, Illinois, (312)-236-7292.

③ Fugitive Dust From Coal Preparation

Fugitive or stack particulate emissions from the coal preparation plant are negligible because no thermal drying or onsite open coal storage is employed.

Because the entire preparation facility is enclosed and the preparation circuit is operated in a wet mode, there is little opportunity for fugitive dust emissions from the plant.¹ Typical enclosed silo type coal storage would add little to these emissions if used. Exposed pile storage (seldom used in the east) could be the source of windblown dust if no dust control measures such as compacting, water sprays, or surface coatings are used.

If thermal drying of coal were used in this plant design, either to facilitate dry processing or for shipment preparation, dust emissions to the environment would occur. The uncontrolled emissions from three popular coal drying systems range from 15 to 25 pounds of dust per ton of coal processed. The emissions to the atmosphere could be reduced to less than .075 pound per ton using cyclones followed by wet scrubbing.¹

The low-level fugitive dust emission characteristics of total wet circuit processing plants are generally applicable to all plant sizes. The emissions factors for thermal drying are directly applicable to any size of processing unit.¹

Reference

1. U.S. Environmental Protection Agency, Compilation of Air Pollutant Emission Factors, Third Edition, including supplements 1-7, PB 275-525, August 1977, pp. 346-347.

④ Solid Waste From Coal Preparation

The solid wastes discharged by the coal preparation plant amount to 0.525×10^6 tons/yr.

Solid waste discharged from the preparation plant consists of approximately 93 percent rock, slate, and shale; 2 percent coal fines rejected in the cleaning process; and 5 percent pyritic material.^{1,2} The exact composition of this material will vary widely from coal to coal and as site mining conditions change, but the coal content will be kept to a minimum.² Analyzed samples of contemporary coal preparation plant waste piles show concentrations of pyritic material ranging from 7.7 percent for fines (the size fraction in which pyrites would be expected to concentrate) to 3.1 percent in course rewash refuse.²

The calculation is as follows:

$$\text{Coal preparation waste} = (\text{Rejection rate})(\text{ROM coal feed rate})$$

For the typical plant,

$$\begin{aligned}\text{Coal preparation waste} &= (0.27)(6.7 \times 10^3 \text{ tons/day}) \\ &= 1800 \text{ tons/day}\end{aligned}$$

On a yearly basis,

$$\begin{aligned}\text{Coal preparation waste} &= (1800 \text{ tons/day})(0.8 \text{ capacity factor})(365 \text{ days/yr}) \\ &= 0.525 \times 10^6 \text{ tons/yr}\end{aligned}$$

This material is transported with associated moisture (10 to 15 percent) to nearby surface landfill where it will be compacted and rehabilitated through revegetation and stabilization techniques.³ Such sites must be designated and permitted by state/local authorities. Section III discusses land requirements for solid waste disposal. Water control must be installed for both surface and subsurface drainage of the area.

The production of solid waste for a given coal and a given preparation plant is linearly scaleable for changes in plant coal use. As more rock or slate enters in the ROM coal, as in coal from thinner seams, the rock refuse fraction can be expected to rise accordingly, but the coal fines fraction and the pyritic material fraction can be expected to remain constant, based on the clean coal plant output.

References

1. U.S. Environmental Protection Agency, "Environmental Assessment of Coal Cleaning Processes: Technology Overview," EPA-600/7-79-073e, September 1979, p. 47.
2. C. Treworgy, Illinois Geological Survey, In House Studies of Processing Wastes, April 2, 1980.
3. Federal Register, "Surface Coal Mining and Reclamation Operations, Permanent Regulatory Program," Vol. 44, No. 50, March 13, 1979, pp. 15435-15439.

⑤ Surface Runoff From Coal Preparation Waste Storage

Surface runoff for coal processing disposal sites is, in general, not quantifiable because it depends on rainfall and subsurface water quantities that may come in contact with the waste material.¹

Runoff from coal cleaning refuse waste piles will originate from two sources: rainfall on the surface of the fill and subsurface water including moisture on the surface of the material. The requirement to cover with "topsoil" and revegetate and control drainage on the surface of the disposal area will, in general, isolate the rainfall and surface water from the waste material.^{1,2} Subsurface water can more readily come in contact with the waste material and this contact can result in the dissolving of solids (forming, for example, sulfates); the acidification of the liquids; or the deposition of suspended solids in the liquid. It is possible that a properly designed and operated drainage system will result in acceptable water quality for discharge to surface waters. If this quality cannot be achieved, treatment of the drainage from the area may be necessary to meet local regulations for dissolved solids, suspended solids, and acidity.³

For this processing plant, the dry landfill method of disposal has been chosen. As the surface area of the fill increases, there will be a general increase in the opportunity for ingress of surface (rain) water and for intrusions of subsurface water. Neither of these sources can be accurately quantified.

References

1. U.S. Environmental Protection Agency, "Environmental Assessment of Coal Cleaning Processes: Technology Overview," EPA-600/7-79-073e, September 1979, p. 48.
2. Federal Register, "Surface Coal Mining and Reclamation Operations, Permanent Regulatory Program," Vol. 44, No. 50, March 13, 1979, pp. 15434-15436 and 15424-15430.
3. Personal Communication, Harry Chappel, Illinois Environmental Protection Agency, April 3, 1980.

⑥ Fugitive Dust From Onsite Coal Storage

It is not possible to accurately quantify the fugitive dust emissions from the coal storage area. Wind erosion resulting in airborne dust should not be a significant air pollution source for active piles if dust control measures are maintained.

Coal fines are an inevitable^{1,2} result of coal preparation and handling operations. Dust emissions from the storage areas, especially active storage, can be effectively controlled through the use of water sprays and surface compaction. In addition, oil, asphalt, or latex coatings can be applied to long-term storage piles to control dust emissions. It should also be noted that the surface of a properly compacted long-term storage pile will quickly lose the fines, which can become airborne, and the dust emissions will drop to a very low level unless the pile is physically disturbed.

The dust emissions from an open coal storage pile are not, in general, quantifiable. They are, however, proportional to the exposed surface of the coal pile and generally will increase with increases in surface wind velocity.²

References

1. T.H. Pigford et al., "Fuel Cycles for Electrical Power Generation EEED-101 Teknekron, Inc., Berkeley, California, January 1973.
2. U.S. Environmental Protection Agency, "Survey of Fugitive Dust From Coal Mines," EPA-908/1-78-003, February 1978, pp. 2 and 56.

⑦ Controlled Runoff From Onsite Coal Storage

It is not possible to accurately quantify the liquid runoff from the coal storage areas because the source of this liquid is primarily rainfall and, to a lesser extent, the water sprays that may be used to control dust.¹

Surface water is excluded from the area by a liner, usually clay or an impermeable membrane. Water that falls on the surface of the coal pile will either be lost to the air through evaporation or be drained to a peripheral drainage channel where it can be routed to the power plant water treatment system. This water may contain suspended solids and dissolved solids; be slightly acidic; and contain oil, if oil sprays are used in dust control. The receiving water treatment system is designed to handle such pollutants through settling, neutralization, oil removal, and blending to achieve acceptable water quality for either recycling uses in the system or discharge to surface water.

The quantity of runoff is generally proportional to the surface area of the coal storage pile and the relative quantity of precipitation at the site.

Reference

1. U.S. Environmental Protection Agency, "Environmental Assessments of Coal Cleaning Processes: Technology Overview," EPA-600/7-79-073e, September 1979, pp. 44 and 45.

⑧ Coal Feed to Generating Plant

The amount of prepared coal required for the typical plant assumed in this ECIR is 1.43×10^6 tons/yr.

To determine how much coal is required to run any given power plant, the following information is needed:

- Net power delivered to the transmission grid (P) in MWe
- Net station heat rate ($\dot{Q}$) in Btu/kWh
- Heat content of coal, as fired (Q) in Btu/lb

The power delivered to the grid is known for a given plant (i.e., the nominal rating of 500 MWe, 1000 MWe, etc.)

The net station heat rate ($\dot{Q}$), which varies from plant to plant, is a measure of the amount of heat (Btu) that must be fed into the boiler to get 1 kWh of electricity out to the grid. Net power delivered to the grid equals total power generated minus power required to operate plant auxiliaries, including environmental control equipment. The actual overall plant heat rate is listed in the plant's major documents, such as the Environmental Impact Statement or the Power Plant Design Report.

The heat content of coal (Q) as fired is a parameter given in the coal analysis.

Using the above definitions, the coal required on a daily basis is as follows:

$$\frac{(P)(\dot{Q})}{Q} \left[\left(\frac{1 \times 10^3 \text{ kWe}}{\text{MWe}} \right) \left(\frac{1}{2 \times 10^3} \frac{\text{ton}}{\text{lb}} \right) \left(2.4 \times 10 \frac{\text{hr}}{\text{day}} \right) \right] = 12 P\dot{Q}/Q \text{ tons/day}$$

In the typical plant,

$$\begin{aligned} P &= 500 \text{ MWe} \\ \dot{Q} &= 9760 \text{ Btu/kWh} \\ Q &= 12,000 \text{ Btu/lb} \end{aligned}$$

Thus, for the typical plant,

$$\begin{aligned} \text{Coal feed rate} &= 12 P\dot{Q}/Q \text{ tons/day} \\ \text{Coal feed rate} &= \frac{12 (500 \text{ MWe})(9760 \text{ Btu/kWh})}{12,000 \text{ Btu/lb}} \\ &= 4.9 \times 10^3 \text{ tons/day} \end{aligned}$$

On a yearly basis,

$$\begin{aligned}\text{Coal feed rate} &= (4.9 \times 10^3 \text{ tons/day})(0.8 \text{ capacity factor})(365 \text{ days/yr}) \\ &= 1.43 \times 10^6 \text{ tons/yr}\end{aligned}$$

The analysis for the coal used in this ECIR is as follows¹:

Proximate Analysis (%)

ash	8.8
fixed C	44.3
volatile	38.7
moisture	8.2

Ultimate Analysis (%)

C	64.9
O	8.7
H	4.6
N	1.5
S	3.3
ash	8.8
moisture	8.2

Heat value 12,000 Btu/lb

In subsequent sections of this ECIR, values from this coal analysis are used to calculate the resources and residuals associated with operation of the plant, e.g., in item (14) the ash content of the coal is used to calculate the amount of bottom ash from combustion. If a coal different from the one shown in the above table were used, the values from the new coal analysis would be substituted in the equations.

In the calculations of environmental pollutants, it is assumed that 20 percent of the ash is emitted as bottom ash and that the remaining 80 percent is emitted from the boiler as fly ash.^{2,3} It is also assumed that 10 percent of the sulfur is retained in the bottom ash and fly ash or removed as a result of pyrite removal in the coal pulverizer, and the remaining 90 percent is converted to sulfur dioxide.^{4,5}

energy content of the coal feed into the boilers is converted into electricity with an efficiency of 35 percent. The remainder of the energy is lost in the form of thermal energy according to the following table.⁶

	Percent of Input	Energy at 100-Percent Capacity (Btu/day)
Net Electrical Output	35	41×10^9
Heat Rejected to Condenser	50	58.5×10^9
Sensible Heat in Flue Gas	10.7	12.5×10^9
Internal Thermal Losses and Plant Consumption	4.3	5×10^9
<hr/>		
Total Energy From 4.9×10^3 tons/day Coal Feed at 12,000 Btu/lb	100	117×10^9

These heat losses pose little environmental concern: the heat rejected directly to the atmosphere is negligible, the heat rejected to the main condenser is cooled by closed-cycle cooling towers, and heat rejected through the cooling tower blowdown line is dissipated into the atmosphere through water treatment/recycling facility holding ponds.

References

1. G.K. Nielsen, ed., 1978 Keystone Coal Industry Coal Manual, Kentucky #11 Coal, McGraw-Hill, New York, New York, 1978.
2. U.S. Environmental Protection Agency, "Electric Utility Steam Generating Units: Background Information for Proposed Particulate Emission Standards," EPA-450/2-78-006a, July 1978, p. 3-14.
3. Teknekron, Inc., "Comprehensive Standards: The Power Generation Case," EPA No. 68-01-0561, March 1975, p. 91.
4. Personal Communication, Robert Statnick, (202) 426-2683, Senior Staff Engineer, Office of Energy, Minerals, and Industry, Office of Research and Development, U.S. Environmental Protection Agency, Washington, D.C., April 1980.
5. Personal Communication, Walter Stevenson, (919) 541-5477, Staff Scientist, Office of Air Quality, Planning, and Standards, U.S. Environmental Protection Agency, Raleigh-Durham, North Carolina, April 1980.
6. Teknekron, Inc., "Towards Comprehensive Standards: The Electric Power Case," EPA No. 68-01-0561, January 1973, p. 70.

⑨ Evaporative and Drift Losses From Wet Cooling Towers

Evaporative losses from the cooling towers into the atmosphere are approximately 2×10^9 gal/yr for a typical 500-MWe power plant operating at full load. Additionally, another 0.25 percent or 5×10^6 gal/yr will be lost in the form of drift if drift eliminators are not used.

The above values are based on the assumptions that 50 percent of the gross heat released from coal combustion is dissipated to the circulating water system and that the water heat of vaporization at standard conditions is 1050 Btu/lb water evaporated.^{1,2,3} In general, the water requirements due to cooling tower evaporation are given by

$$W_{EVAP}, \text{ gal/day} = 2880 (\text{percent heat rejected to circulating water system}) \cdot \dot{Q}_P / (\text{water heat of vaporization})$$

For the typical plant,

$$\begin{aligned} W_{EVAP} &= (2880)(0.50)(9760 \text{ Btu/kWh})(500 \text{ MWe}) / (1050 \text{ Btu/lb}) \\ &= 6.7 \times 10^6 \text{ gal/day} \end{aligned}$$

On a yearly basis,

$$\begin{aligned} W_{EVAP} &= (6.7 \times 10^6 \text{ gal/day})(0.8 \text{ capacity factor})(365 \text{ days/yr}) \\ &= 2 \times 10^9 \text{ gal/yr} \end{aligned}$$

Similarly, requirements due to cooling tower drift for the typical plant are

$$\begin{aligned} W_{DRIFT} &= 0.0025 W_{EVAP} \\ &= 0.0025 (6.7 \times 10^6 \text{ gal/day}) \\ &= 16.8 \times 10^3 \text{ gal/day} \end{aligned}$$

On a yearly basis,

$$\begin{aligned} W_{\text{DRIFT}} &= (16.8 \times 10^3 \text{ gal/day})(0.8 \text{ capacity factor})(365 \text{ days/yr}) \\ &= 4.91 \times 10^6 \text{ gal/yr} \end{aligned}$$

These cooling tower losses may interact with the local meteorology and cause visibility impairment, fogging, or icing conditions. There are existing regulations limiting cooling tower losses to the atmosphere.

References

1. R.F. Probst and H. Gold, Water in Synthetic Fuel Production: The Technology and Alternatives, The MIT Press, 1978, pp. 47-81.
2. Water Purification Associates, "Final Report: An Assessment of Minimum Water Requirements for Steam-Electric Power Generation and Synthetic Fuel Plants in the Western United States," prepared for Science and Public Policy Program, University of Oklahoma, Contract No. 68-01-1916, August 24, 1976, pp. 61-105.
3. Power Handbook: Basic Power Facts Made Easy, Part One and Part Two, Power Magazine, 1975, p. 104.

10 Cooling Tower Blowdown

Cooling tower blowdown represents approximately 10 percent of the evaporation losses.^{1,2} For a typical plant, blowdown is 0.2×10^9 gal/yr and goes to the water treatment/recycling facility to be reused as makeup water.

Blowdown water typically contain the following environmental residuals: Cides (e.g., chlorine), added for marine and biological growth control; corrosion inhibitors (e.g., chromates), a high concentration of total dissolved solids; and excess heat. Because these residuals are collected and controlled in the water treatment/recycling facility, there is no direct influence on the environment (see item (15)).

For any plant,

$$W_{\text{BLOWDOWN}} = 0.1 W_{\text{EVAP}}$$

For the typical plant,

$$W_{\text{BLOWDOWN}} = 0.1 (6.7 \times 10^6 \text{ gal/day})$$

$$W_{\text{BLOWDOWN}} = 0.7 \times 10^6 \text{ gal/day}$$

On a yearly basis,

$$\begin{aligned} W_{\text{BLOWDOWN}} &= (0.7 \times 10^6 \text{ gal/day})(0.8 \text{ capacity factor})(365 \text{ days/yr}) \\ &= 0.2 \times 10^9 \text{ gal/yr} \end{aligned}$$

References

1. R.F. Probstein and H. Gold, Water in Synthetic Fuel Production: The Technology and Alternatives, The MIT Press, 1978, p. 47.
2. Water Purification Associates, "Final Report: An Assessment of Minimum Water Requirements for Steam-Electric Power Generation and Synthetic Fuel Plants in the Western United States," prepared for Science and Public Policy Program, University of Oklahoma, Contract No. 68-01-1916, August 24, 1976, p. 69.

11 Cooling Tower Makeup

Approximately 2.2×10^9 gal/yr are needed to make up cooling tower losses due to drift, evaporation, and blowdown for a typical plant.

Cooling tower makeup is obtained by summing W_{EVAP} and W_{DRIFT} from item 9 and $W_{BLOWDOWN}$ from item 10 as follows:

$$W_{TOW} = W_{EVAP} + W_{DRIFT} + W_{BLOWDOWN}$$

For the typical plant,

$$\begin{aligned} W_{TOW} &= (6.7)(10^6 \text{ gal/day} + 0.02)(10^6 \text{ gal/day} + 0.67)(10^6 \text{ gal/day}) \\ &= 7.4 \times 10^6 \text{ gal/day} \end{aligned}$$

On a yearly basis,

$$\begin{aligned} W_{TOW} &= (7.4 \times 10^6 \text{ gal/day})(0.8 \text{ capacity factor})(365 \text{ days/yr}) \\ &= 2.2 \times 10^9 \text{ gal/yr} \end{aligned}$$

The above analysis is for a wet cooling system only. When water is expensive, however, (greater than about \$0.80/10³ gallons) or of limited availability, combined wet and dry cooling systems would be used. For such systems, the average annual water consumption is between 10 and 25 percent of the all wet system.¹

Reference

1. R.F. Probstein and H. Gold, Water in Synthetic Fuel Production: The Technology and Alternatives, The MIT Press, 1978, pp. 47-81.

⑫ Miscellaneous Plant Drains

The typical liquid waste flow from miscellaneous plant drains is 175×10^6 gal/yr, all of which goes to the water treatment/recycling facility.¹

The liquid waste consists of various water streams used in maintaining plant operation (e.g., boiler blowdown and bearing cooling) and can be slightly contaminated with oil or chemicals. The waste figure given above was taken from an operating 500-MWe power plant.¹ Because the magnitude of the waste stream is not a linear function of plant power level, the waste from a power plant of a size other than 500 MWe should be obtained from an actual plant of that size. Such information is contained in the plant's Environmental Impact Statement.

The chemical nature of the waste stream as potentially released to the environment is discussed in item ⑮.

Reference

1. Environmental Analysis, Spurlock Station Unit No. 2, Docket No. 6500-05, July 1975, p. II-54.

⑬ Makeup Water to Generating Plant

The makeup water to the generating plant is 180×10^6 gal/yr.

Makeup water is required for two purposes: for the operations discussed in item ⑫ and for handling bottom ash from the boiler.

Bottom ash is collected and quenched in water-filled hoppers before it is sluiced to a disposal site. The rate at which water is evaporated from the hopper, W_{VAP} , is a function of the ash specific heat, temperature drop, quenching rate, and water heat of vaporization, i.e.,

$$W_{VAP}, \text{ gal/day} = 240 (\text{ash fraction in coal})(\text{coal feed rate})(\text{bottom ash fraction}) \\ (\text{bottom ash temperature change})(\text{bottom ash specific heat}) / \\ (\text{water heat of vaporization})$$

For the typical plant, if it is assumed that

Ash removal temperature	= 1200° F
Ash quenched temperature	= 200° F
Ash specific heat	= 0.2 Btu/lb-° F
Water heat of vaporization	= 1.050×10^3 Btu/lb
Bottom ash fraction	= 0.2

then

$$W_{VAP} = 240 (0.088)(4.9 \times 10^3 \text{ tons/day})(0.2)(1000^\circ\text{F})(0.2 \text{ Btu/lb-}^\circ\text{F}) / (1050 \text{ Btu/lb}) \\ = 3.9 \times 10^3 \text{ gal/day}$$

On a yearly basis,

$$W_{VAP} = (3.9 \times 10^3 \text{ gal/day})(0.8 \text{ capacity factor})(365 \text{ days/yr}) \\ = 1.14 \times 10^6 \text{ gal/yr}$$

Of equal importance to the water evaporated is the amount of excess water needed for bottom ash handling and disposal, W_{HAD} . If the weight of water remaining in the quenched ash is 30 percent of the ash weight, then

$$W_{HAD}, \text{ gal/day} = 72 (\text{ash fraction in coal})(\text{coal feed rate})(\text{bottom ash fraction})$$

For the typical plant,

$$\begin{aligned} W_{HAD} &= 72 (0.088)(4.9 \times 10^3 \text{ tons/day})(0.2) \\ &= 6.2 \times 10^3 \text{ gal/day} \end{aligned}$$

On a yearly basis,

$$\begin{aligned} W_{HAD} &= (6.2 \times 10^3 \text{ gal/day})(0.8 \text{ capacity factor})(365 \text{ days/yr}) \\ &= 1.81 \times 10^6 \text{ gal/yr} \end{aligned}$$

The total water requirement for bottom ash disposal, W_{BA} , is therefore given as

$$W_{BA} = W_{VAP} + W_{HAD}$$

For the typical plant,

$$\begin{aligned} W_{BA} &= (3.9)(10^3 \text{ gal/day} + 6.2)(10^3 \text{ gal/day}) \\ &= 10.1 \times 10^3 \text{ gal/day} \end{aligned}$$

On a yearly basis,

$$\begin{aligned}W_{BA} &= (10.1 \times 10^3 \text{ gal/day})(0.8 \text{ capacity factor})(365 \text{ days/yr}) \\&= 3 \times 10^6 \text{ gal/yr} \\&= 0.03 \times 10^8 \text{ gal/yr}\end{aligned}$$

The majority of this water will be supplied from recycled water (see item 16). Thus, the total makeup water requirement for the generating plant is the 1.75×10^8 gal/yr for general plant operations (see item 12) plus the 0.03×10^8 gal/yr given above, or 1.78×10^8 gal/yr $\approx 180 \times 10^6$ gal/yr.

Reference

1. Water Purification Associates, "Final Report: An Assessment of Minimum Water Requirements for Steam-Electric Power Generation and Synthetic Fuel Plants in the Western United States," prepared for Science and Public Policy Program, University of Oklahoma, Contract No. 68-01-1916, Chapter 8, August 24, 1976, p. 141.

14 Bottom Ash From Coal Combustion

The amount of bottom ash generated is 25×10^3 tons/yr.

As described earlier, the quantity of ash in the coal assumed for this ECIR is 8.8 percent, and 20 percent of this ash becomes bottom ash.^{1,2} Thus,

$$\text{Bottom ash} = (\text{ash fraction in coal})(\text{coal feed rate})(\text{bottom ash fraction})$$

For the typical plant:

$$\begin{aligned}\text{Bottom ash} &= (0.088)(4.9 \times 10^3 \text{ tons/day})(0.20) \\ &= 86 \text{ tons/day}\end{aligned}$$

On a yearly basis,

$$\begin{aligned}\text{Bottom ash} &= (86 \text{ tons/day})(0.8 \text{ capacity factor})(365 \text{ days/yr}) \\ &= 25 \times 10^3 \text{ tons/yr}\end{aligned}$$

Bottom ash from a dry bottom pulverized coal boiler is collected and quenched in hoppers, located beneath the boiler, where it is sluiced with water to settling ponds or dewatering bins.³

References

1. U.S. Environmental Protection Agency, "Electric Utility Steam Generating Units: Background Information for Proposed Particulate Emission Standards," EPA-450/2-78-006a, July 1978, p. 3-14.
2. Teknekron, Inc., "Comprehensive Standards: The Power Generation Case," EPA No. 68-01-0561, March 1975, p. 91.
3. Water Purification Associates, "Final Report: An Assessment of Minimum Water Requirements for Steam-Electric Power Generation and Synthetic Fuel Plant in the Western United States," prepared for Science and Public Policy Program, University of Oklahoma, Contract No. 68-01-1916, August 24, 1976, p. 142.

15 Excess Water to River or Sewer

Whenever the holding pond from the water treatment/recycling facility overflows during low demand periods, the excess water is directed to the area surface waters (lake or river) or to a sewer system.

The quantity and quality of the overflow is controlled to within standards established by either the Federal Government or the state based National Pollutant Discharge Elimination System (NPDES) procedures and guidelines. Projections for the typical coal-fired 500-MWe power plant show that the maximum flow rate from the holding ponds under worst-case conditions is 26×10^6 gal/day.⁴ The maximum daily average concentration of controlled residuals observed for 30 consecutive days and the amount of residuals that would be released at the maximum flow rate are as follows:⁴

<u>Residual</u>	<u>Maximum Amount Released</u>	<u>Maximum Measured Concentration (mg/l)</u>	<u>Kentucky Water Quality Standards (mg/l)</u>
Total Suspended Solids	3.3 tons/day	30	30
Oil and Greases	1.7 tons/day	15.2	None
Copper	2 lb/day	0.009	1
Iron	2 lb/day	0.009	1
Chlorine	24.2 lb/day	0.11	None

Where

$$\text{Maximum amount released per day} = (\text{Maximum flow rate}) \left(\frac{\text{Maximum average 30-day concentration}}{\text{Maximum average 30-day concentration}} \right)$$

The allowable concentrations of the pollutants shown above are specified by the appropriate state NPDES permitting authority⁵ based on Federal regulations in the Clean Water Act, local pollutant regulations, and the water quality characteristics of the receiving water.

The 26×10^6 gal/day worst-case discharge is not characteristic of the expected flow. The actual flow would be considerably lower and would depend on site-specific conditions, such as precipitation.

References

1. Federal Water Pollution Control Act, P.L. 92-500 (as ammended), 1972.
2. Clean Water Act, P.L. 95-217, 1977.
3. U.S. Environmental Protection Agency, "A Guide to New Regulations for the NPDES Permit Program," C-1, June 1979.
4. Environmental Analysis, Spurlock Station Unit No. 2, Docket No. 6500-05, July 1975, p. II-55.
Personal Communication, Division of Water Quality, Kentucky Department of Natural Resources and Environmental Protection, (502) 564-2126.

16 Recycle Water

Recycled water can be used for the solid waste handling requirement of 2.9×10^7 gal/yr.

Recycle water in this plant configuration is water that has been withdrawn from the plant water treatment system after settling, oil removal, acidic neutralization. This water will contain varying degrees of dissolved solids as well as suspended particulates. In general, it will be of such quality that it could be discharged to surface waters.

The amount of water required in solid waste handling systems, assuming a 50-percent total solids mixture is given by

$$\begin{aligned} \text{Water required, gal/day} = & 240 [(\text{bottom ash, dry}) + (\text{fly ash, dry}) \\ & + (\text{scrubber sludge, dry}) - (\text{water in scrubber sludge})] \end{aligned}$$

For the typical plant,

$$\begin{aligned} \text{Water required} = & 240 [86 \text{ tons/day} + 345 \text{ tons/day} + 660 \text{ tons/day} - 660 \text{ tons/day}] \\ = & 0.1 \times 10^6 \text{ tons/day} \end{aligned}$$

On a yearly basis,

$$\begin{aligned} \text{Water required} = & (0.1 \times 10^6 \text{ gal/day})(0.8 \text{ capacity factor})(365 \text{ days/yr}) \\ = & 2.9 \times 10^7 \text{ gal/yr} \end{aligned}$$

The amount of recycle water required for ash handling is directly and linearly scalable with plant capacity for a given coal and scrubber operation and will increase linearly as the dry solids to be transferred increase.

Reference

1. Final Environmental Impact Statement, Spurlock Station Unit No. 2, and Associated Transmission, USDA-REA-EIS-76-4F, November 1976.

17 Fly Ash From Particulate Control

The total amount of fly ash generated is 100×10^3 tons/yr.

Dry electrostatic precipitators are used to remove the coal fly ash from the flue gas. Eighty percent of the ash in the coal is emitted as fly ash,^{1,2} or

$$\text{Fly ash} = (\text{ash fraction in coal})(\text{coal feed rate})(\text{fly ash fraction})$$

For the typical plant,

$$\begin{aligned}\text{Fly ash} &= (0.088)(4.9 \times 10^3 \text{ tons/day})(0.80) \\ &= 345 \text{ tons/day}\end{aligned}$$

On an annual basis,

$$\begin{aligned}\text{Fly ash} &= (345 \text{ tons/day})(0.8 \text{ capacity factor})(365 \text{ days/yr}) \\ &= 100 \times 10^3 \text{ tons/yr}\end{aligned}$$

To meet the current NSPS of $0.03 \text{ lb}/10^6 \text{ Btu}$, only 0.5 percent of this amount is emitted to the ambient atmosphere, and 99.5 percent is captured by the electrostatic precipitator.

From these precipitators, the collected ash is discharged into storage hoppers by rapping. The dry fly ash is transported by pneumatic conveying from the precipitator to the sluicing system, where it will become part of the bottom ash scrubber sludge mixture.³

A second particle control technology now in use and gaining in popularity is the baghouse. Although the technology has been applied to large utility plants both in the East and in the West, it is more predominantly applied in the West to collect the high resistivity fly ash from western coals that is difficult to collect in an ESP⁴ and to meet more stringent particulate emission standards imposed by some western states. Baghouses generally have higher collection efficiencies than ESPs (96 to 99.5 percent for ESPs versus >99 percent for baghouses in most cases) and are especially effective in the control of fine particles ($<3\mu$). If a baghouse is to be considered,

the assumed collection efficiency of the unit can be directly substituted in the example given in place of the 99.5 percent removal efficiency assumed for the ESP. Although the removal efficiency is variable for both ESPs and baghouses, the individual utilities will generally operate the units to meet the standards that apply in each specific case.

References

1. U.S. Environmental Protection Agency, "Electric Utility Steam Generating Units: Background Information for Proposed Particulate Emission Standards," EPA-450/2-78-006a, July 1978, p. 3-14.
2. Teknekron, Inc., "Comprehensive Standards: The Power Generation Case," EPA No. 68-01-0561, March 1975, p. 91.
3. Water Purification Associates, "Final Report: An Assessment of Minimum Water Requirements for Steam-Electric Power Generation and Synthetic Fuel Plants in the Western United States," prepared for Science and Public Policy Program, University of Oklahoma, Contract No. 68-01-1916, August 24, 1976, p. 144.
4. U.S. Environmental Protection Agency, "Electric Utility Steam Generating Units: Background Information for Proposed Particulate Matter Emission Standards," EPA-450/2-78-006a, July 1978 p. 4-1.

18 Makeup Water for Fly Ash Transport

Water added to the captured fly ash to transport it to the disposal area is 24×10^6 gal/yr.

Dry electrostatic precipitators are used to remove the coal fly ash from the flue gas. In these precipitators, the collected ash is discharged into a sluicing system by rapping. The ash is then combined with recycle water until the mixture is at least 50-percent liquid by weight.¹ Note that the fly ash, bottom ash, and scrubber sludge are all individually fed into the sluicing system.

The amount of water required to transport the ash in the sluicing system is given as

$$\text{Water required, gal/day} = 240 (\text{ash fraction in coal})(\text{coal feed rate})(\text{fly ash fraction})$$

For the typical plant,

$$\begin{aligned}\text{Water required} &= 240 (0.088)(4.9 \times 10^3 \text{ tons/day})(0.8) \\ &= 83 \times 10^3 \text{ gal/day}\end{aligned}$$

On a yearly basis,

$$\begin{aligned}\text{Water required} &= (83 \times 10^3 \text{ gal/day})(0.8 \text{ capacity factor})(365 \text{ days/yr}) \\ &= 24 \times 10^6 \text{ gal/yr}\end{aligned}$$

Reference

1. Electric Power Research Institute, "FGD Sludge Disposal Manual," FP-977, January 1979, p. 4-7, Table 4-2.

①9 Sludge From SO₂ Control

The amount of scrubber sludge generated (on a dry basis) is 193×10^3 tons/yr.

The use of a limestone scrubber is assumed for SO₂ control based on the current number of such units in operation and their combined record of effectiveness and reliability. The operation of such units involves the creation and requirement for disposal of sludge (spent reactants mixed in the same ratio with water).

The quantity of sulfur in the coal used is 3.3 percent. Therefore, the quantity of sulfur entering the boiler is

$$\begin{aligned} S &= (\text{sulfur fraction in coal})(\text{coal feed rate}) \\ &= 0.033 (4.9 \times 10^3 \text{ tons/day}) \\ &= 162 \text{ tons/day} \end{aligned}$$

If it is assumed that a total of 10 percent of the sulfur is retained in the bottom ash and fly ash or removed as a result of pyrite removal in the coal pulverizer, and that the remainder of the sulfur is converted to SO₂, then

$$\begin{aligned} \text{SO}_2 &= 0.9 (\text{sulfur entering boiler})(2) \\ &= 0.9 (162 \text{ tons/day})(2) \\ &= 292 \text{ tons/day} \end{aligned}$$

Thus, 292 tons/day of SO₂ enter the scrubber.¹⁻⁴ (Note: The factor "2" in this equation is used because every mole of sulfur requires 1 mole of oxygen to form 1 mole of SO₂.) As will be shown in item 22, the amount of dry limestone used is 500 tons/day, i.e., 1.25 times the stoichiometric requirement. This excess 25 percent of the stoichiometric requirement will become part of the sludge residue. It is generally accepted⁵ that the spent slurry consists of 75 percent CaSO₃·½H₂O and 25 percent CaSO₄·2H₂O. As will be shown in item 23, the scrubber must operate at 88 percent efficiency to meet the standard. Consequently, the amount of scrubber sludge (dry basis) generated each day is

$$\begin{aligned} \text{Sludge} &= [0.25 (100/64) + (140/64)](\text{scrubber efficiency})(\text{SO}_2 \text{ feed rate}) \\ &= [0.25 (100/64) + (140/64)](0.88)(292 \text{ tons/day}) \\ &= 660 \text{ tons/day} \end{aligned}$$

On a yearly basis,

$$\begin{aligned}\text{Sludge} &= (660 \text{ tons/day})(0.8 \text{ capacity factor})(365 \text{ days/yr}) \\ &= 193 \times 10^3 \text{ tons/yr}\end{aligned}$$

where

100/64 = limestone/SO₂ molecular weight ratio

140/64 = (CaSO₃·½H₂O and CaSO₄·2H₂O) mixture/SO₂ molecular weight ratio

Based on current usage and projections of new installations, lime/limestone scrubbers are the most popular form of SO₂ control now available and are expected to remain so in the foreseeable future. Other SO₂ control systems have been demonstrated at utility scale, however. These include sodium carbonate scrubber systems, dual alkali scrubber systems, Wellman-Lord regenerative scrubber systems, magnesium oxide regenerative scrubber systems, and dry lime or alkali injection systems. Although these systems are now or have been in commercial operation, their overall number is small and for this reason have not been included in the detailed evaluation of control technology. The major points of environmental interest for these systems are generally the same as those for lime/limestone. The interest in these systems centers primarily on their potential for desirable modification or reduction in the waste (generally considered solid waste) streams from the process.

Although the current NSPS for SO₂ control excludes the use of low-sulfur coal alone to achieve compliance, low-sulfur coal can be used in combination with other SO₂ removal techniques to achieve a more desirable system from the standpoint of reliability, economics, or both. For those plants operating under the previous Federal NSPS, the use of low-sulfur coal is a viable option to achieve the 1.2 lb/10⁶ Btu SO₂ emission limit. Older plants, not controlled by Federal regulations, may also use low-sulfur coal to comply with applicable state and local SO₂ standards.

References

1. Personal Communication, Robert Statnick, (202) 426-2683, Senior Staff Engineer, Office of Energy, Minerals, and Industry, Office of Research and Development, U.S. Environmental Protection Agency, Washington, D.C.
2. Communication, Walter Stevenson, (919) 541-5477, Staff Scientist, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Raleigh-Durham, North Carolina, April 1980.
3. U.S. Environmental Protection Agency, "Electric Utility Steam Generating Units: Background Information for Proposed SO₂ Emission Standards," EPA-450/2-78-007a, July 1978.
4. U.S. Environmental Protection Agency, "Position Paper on Regulation of Atmospheric Sulfates," EPA-450/2-75-007, September 1975.
5. Aerospace Corporation, "Controlling SO₂ Emissions from Coal-Fired Steam-Electric Generators: Solid Waste Impact, Vol. II. Technical Discussion," EPA-600/7-78-0446, March 1978.

20 Solid Waste Handling

The typical plant and associated pollutant controls generate 320×10^3 tons/yr (dry basis) of solid sludge.

Waste streams entering the disposal site contain pyrites sluiced from the coal pulverizer and bottom ash sluiced from the boiler, fly ash sluiced from electrostatic precipitator, and scrubber sludge underflow from a thickener located downstream of the scrubber. The scrubber wastes in the disposal site settle to approximately 50 percent solids. Excess water, i.e., from the settling of the scrubber sludge and unevaporated rainwater, is returned to the water treatment/recycle facility.

The wastes are contained in impoundments formed by the excavation of the disposal site. Sides of the impoundment are sloped and extend above grade level to complete the basin and form berms and dikes around the periphery of the site. A total depth of 30 feet of waste material is considered typical.

For the typical plant, determination of total solid wastes on a dry basis and required land area are as follows:

1. 86 tons/day bottom ash
 345 fly ash
 560 reacted limestone ($75\%:\text{CaSO}_3 \cdot \frac{1}{2} \text{H}_2\text{O}$ & $25\%:\text{CaSO}_4 \cdot 2 \text{H}_2\text{O}$)¹
+100 unreacted limestone
 1100 tons/day (solids, dry) at 88.6 lb/ft³
2. Adding sluicing water results in
+1100 tons/day (sluicing water)
 2200 tons/day wet waste
3. To determine land required:²

$$\left(\frac{2200 \text{ tons}}{\text{day}} \right) \left(\frac{2000 \text{ lb}}{\text{ton}} \right) \left(\frac{1 \text{ ft}^3}{88.6 \text{ lb}} \right) \left(\frac{1}{30 \text{ ft}} \times \frac{1 \text{ acre}}{43,560 \text{ ft}^2} \right) (1.1, \text{ impoundment size factor})$$

$$\left(\frac{365 \text{ days}}{\text{year}} \right) = 15.3 \frac{\text{acres}}{\text{year}}$$
4. This results in a land acreage requirement of

$$\left(\frac{15.3 \text{ acres}}{\text{year}} \right) \left(\frac{30 \text{ years}}{\text{life}} \right) = 460 \text{ acres at 100 percent capacity factor}$$

On an annual basis,

$$\begin{aligned}\text{Sludge} &= (1100 \text{ tons/day})(0.8 \text{ capacity factor})(365 \text{ days/yr}) \\ &= 320 \times 10^3 \text{ tons/yr}\end{aligned}$$

and

$$\begin{aligned}\text{Land requirement} &= (460 \text{ acres/yr})(0.8 \text{ capacity factor}) \\ &= 370 \text{ acres for 30 years, 30 feet deep}\end{aligned}$$

Regardless of the solid waste treatment or stabilization method used, upon filling of the disposal impoundment, it is expected that a layer of soil will be placed over the wastes and will be graded and sloped to encourage rainwater runoff and to minimize seepage of rainwater through the wastes.

Three alternative sludge treatment and stabilization methods are available for disposal of the wastes: (1) Settling the wastes over an impervious layer and decanting of supernatant liquid; the impervious material can be clay or an elastomeric liner with a permeability coefficient of 10^{-7} cm/sec or less. (2) Reducing the leachability of the waste (to 10^{-5} to 10^{-7} cm/sec) by chemically treating the scrubber sludge-ash waste with lime, forming a solid material with low permeability characteristics and high load-bearing characteristics.² (3) Installing an underdrainage or dewatering system of perforated pipes in the soil immediately below the sludge-soil interface. Settling of the wastes up to 60 percent solids has been observed.² Further settling to 80 percent solids (with a correspondent reduction of waste volume and disposal land area) can be achieved if the scrubber sludge were oxidized to gypsum within the scrubber or in an oxidation tower downstream of the scrubber.

Decisions on the use of these alternatives will be based on site-specific considerations, including sludge and soil characteristics, land reclamation requirements, and cost factors.

Radon Emanation From Solid Waste Storage

Analysis of the ash produced by the combustion of bituminous coal has shown that a power plant solid waste burial site will emit approximately 2.23×10^{-4} Ci/day of radioactive radon-222 gas for every acre of covered solid waste disposed of. Over a 30-year plant lifetime, radon emissions will

average 4.1×10^{-2} Ci/day for a typical 500-MWe plant, assuming that all of the solid wastes are buried with approximately 2 feet of earth cover at the power plant site and the plant operates at an average capacity factor of 80 percent.

Radon emanation from ash piles is a function of the surface area and depth of the buried waste and the depth of earth cover over the waste. Waste containing radium-226 (the parent nuclide of radon-222 gas) buried at a depth of 10 feet will emit approximately the same amount of radon gas as waste buried in deeper layers because of the self-shielding effect of the waste. Using data collected by the U.S. Geological Survey,³ Goldman has shown that the annual radon-222 gas emissions from Appalachian coal ash waste with a radium-226 concentration of 3.48 pCi/gm would be 0.191 Ci/acre-yr assuming a 25-percent reduction due to a 2-foot earth cover.⁴

Using these data and adjusting for the higher radium-226 concentration assumed in item 23, a radon gas emanation rate factor of 5.69×10^{-4} Ci/day-acre is produced, assuming a 2-foot earth cover and an ash depth of at least 10 feet. This factor must be adjusted downward according to the amount of non-ash waste, e.g., scrubber sludge, in the solid waste piles.

Because radium-226 decays to radon-gas at a very slow rate (the half-life of radium-226 is over 1600 years), it can be assumed that, over the 30-year plant life, radon gas emanation is directly proportional to the waste pile surface area and the amount of ash containing radium-226 in the waste; therefore,

$$\text{Radon gas, Ci/day} = \left(\frac{\text{ash content in solid waste}}{\text{total solid waste disposed}} \right) (\text{surface area of waste piles, acres})$$

$$(5.69 \times 10^{-4} \text{ Ci/day-acre})$$

For the typical plant,

$$\text{Radon gas, Ci/day} = \left(\frac{431 \text{ tons/day bottom and fly ash}}{1100 \text{ tons/day total solid waste}} \right) (\text{surface area of waste piles})$$

$$(5.69 \times 10^{-4} \text{ Ci/day-acre})$$

(See item 20 for solid waste quantities)

$$= (2.23 \times 10^{-4} \text{ Ci/day-acre})(\text{surface area of waste pile, acre})$$

For item (20), the total area necessary for the disposal of solid wastes at a depth of 30 feet over the 30-year lifetime for the typical 500-MWe plant, assuming an 80-percent capacity factor, is 370 acres. Therefore, the average daily radon emission from the burial site over the 30-year plant life is as follows:

$$\begin{aligned}\text{Radon gas} &= (2.23 \times 10^{-4} \text{ Ci/day-acre}) \left(\frac{370 \text{ acres}}{2} \right) \\ &= 4.1 \times 10^{-2} \text{ Ci/day}\end{aligned}$$

The factor of 2 is used to compute the average area of the solid waste burial ground assuming a constant buildup at 10 acres/yr over 30 years (see item (20)).

Therefore, the annual average radon emission, assuming a 80-percent capacity factor, is

$$\begin{aligned}\text{Annual radon gas} &= (4.1 \times 10^{-2} \text{ Ci/day})(365 \text{ days/yr}) \\ &= 14.9 \text{ Ci/yr}\end{aligned}$$

There are no current regulations controlling the release of radon from coal waste storage piles.

References

1. P.P. Leo and J. Rossoff, "Controlling SO₂ Emissions from Coal-Fired Steam-Electric Generators: Solid Waste Impact," EPA-600/7-78-044b, Aerospace Corporation, March 1978.
2. R.B. Fling et al., "Disposal of Flue Gas Cleaning Wastes: EPA Shawnee Field Evaluation - Third Annual Report," EPA-600/7-80-011, Aerospace Corporation, January 1978.
3. V.E. Swanson, "Collection, Chemical Analysis, and Evaluation of Coal Samples," USGA Open File Report 76-468, 1975.
4. M.J. Goldman, "Energy: What About the Waste?" Chemical Engineering Progress, November 1979, p. 65.

21 Makeup Water for SO₂ Control

The amount of makeup water required for flue gas desulfurization is 300×10^6 gal/yr.

For this analysis, a lime/limestone slurry is used in the scrubber, and it is assumed that the flue gas is saturated with water vapor upon leaving the scrubber. Typical conditions at this location are $P = 15.056$ psia, $T = 102^\circ\text{F}$, which correspond to flue gas containing 0.127 mole water/mole dry gas. If the fractional weights of carbon (C), sulfur (S), hydrogen (H), oxygen (X), and water (W) in the coal are known, and 15 percent excess air is assumed, it can be shown that the makeup water requirement per unit weight of coal is given by the following relation:^{1,2}

$$\frac{\text{lb makeup water}}{\text{lb coal}} = 12.8 \left(\frac{C}{12} + \frac{S}{32} \right) + 10.5 \left(\frac{H}{4} - \frac{X}{32} \right) - W - \frac{H}{9}$$

Using the coal feed rate obtained previously, the above equation can be modified to give the required daily water feed rate, W_{FGD}^1 :

$$W_{\text{FGD}}^1, \text{ gal/day} = \left[12.8 \left(\frac{C}{12} + \frac{S}{32} \right) + 10.5 \left(\frac{H}{4} - \frac{X}{32} \right) - W - \frac{H}{9} \right] (2.88 \times 10^3 \frac{\text{lb}}{\text{Q}})$$

In addition to leaving with the flue gas, there is also going to be some water leaving with the solid wastes, e.g., $\text{CaSO}_3 \cdot \frac{1}{2}\text{H}_2\text{O}$ and $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$. It is to be noted that, for the purposes of these calculations, the amount of water of hydration is considered negligible. The amount of water leaving in the solid wastes is a function of the sulfur concentration of coal and the slurry concentration,^{1,2} i.e.,

$$\frac{\text{lb makeup water}}{\text{lb sulfur}} = 5.9 \left(\frac{1-m}{m} \right)$$

where

m = weight fraction of solids in waste

= (weight of solids)/(weight of solids plus water)

The above equation can similarly be modified to give the required daily water feed rate, W_{FGD}^2 :

$$W_{\text{FGD}}^2, \text{ gal/day} = 1.7 \times 10^4 \frac{\text{lb}}{\text{Q}} S \left(\frac{1-m}{m} \right)$$

The total required daily water feed rate is therefore given as

$$W_{FGD} = W_{FGD}^1 + W_{FGD}^2$$

For the typical plant, application of the above equations gives

$$W_{FGD}^1 = 0.80 \times 10^6 \text{ gal/day (vaporized)}$$

$$W_{FGD}^2 = 0.23 \times 10^6 \text{ gal/day (50 percent solids)}$$

$$W_{FGD} = 1.0 \times 10^6 \text{ gal/day}$$

On an annual basis,

$$\begin{aligned} W_{FGD} &= (1.0 \times 10^6 \text{ gal/day})(0.8 \text{ capacity factor})(365 \text{ days/yr}) \\ &= 300 \times 10^6 \text{ gal/yr} \end{aligned}$$

References

1. R.F. Probst and H. Gold, Water in Synthetic Fuel Production: The Technology and Alternatives, The MIT Press, 1978, pp. 40-44.
2. Water Purification Associates, "Final Report: An Assessment of Minimum Water Requirements for Steam-Electric Power Generation and Synthetic Fuel Plants in the Western United States," prepared for Science and Public Policy Program, University of Oklahoma, Contract No. 68-01-1916, August 24, 1976, pp. 110-120.

② Lime/Limestone Requirement for SO₂ Control

The amount of lime/limestone required for flue gas desulfurization is 146×10^3 tons of dry CaCO₃/yr. (The requirement is given solely in terms of limestone because of the relatively large economic penalty incurred if lime is purchased rather than obtained during calcination of limestone.)

For limestone scrubbing, absorbent utilization is generally 0.8¹ (i.e., the calcium-to-sulfur ratio is 1.25) and, as shown in item ②, Figure 2, the scrubber has to achieve 88-percent removal efficiency to satisfy the SO₂ emission standard. The limestone requirement is therefore given by

$$\begin{aligned}\text{Limestone} &= (1.25)(100/64)(\text{SO}_2 \text{ feed rate})(\text{scrubber efficiency}) \\ &= 1.25 (100/64)(292 \text{ ton SO}_2/\text{day})(0.88) \\ &= 500 \text{ tons dry CaCO}_3/\text{day}\end{aligned}$$

where

$$100/64 = \text{limestone/SO}_2 \text{ molecular weight ratio.}$$

On an annual basis,

$$\begin{aligned}\text{Limestone} &= (500 \text{ tons/day})(0.8 \text{ capacity factor})(365 \text{ days/yr}) \\ &= 146 \times 10^3 \text{ tons/yr}\end{aligned}$$

Reference

1. Aerospace Corporation, "Controlling SO₂ Emissions from Coal-Fired Steam-Electric Generators: Solid Waste Impact, Vol. II. Technical Discussion," EPA-600/7-78-044b, March 1978.

23 Flue Gas

The pollutants and trace elements that are part of the flue gas emitted to the ambient atmosphere past control are as follows:

SO ₂	10.2 x 10 ³ tons/yr
NO _x	10.2 x 10 ³ tons/yr
TSP	0.5 x 10 ³ tons/yr
HC	0.22 x 10 ³ tons/yr
CO	0.72 x 10 ³ tons/yr
CO ₂	3.7 x 10 ⁶ tons/yr
As	225 lb/yr
Be	9.3 lb/yr
Cd	4.1 lb/yr
Mn	161 lb/yr
Pb	114 lb/yr
Se	56 lb/yr
Ra	3 x 10 ⁻³ Ci/yr (radioactive)

SO₂

The amount of SO₂ emitted to the ambient atmosphere is 0.6 lb/10⁶ Btu. The current New Source Performance Standards for SO₂ regulation are summarized below.¹

Uncontrolled Emissions (lb SO ₂ /10 ⁶ Btu)	Percent Reduction	Controlled Emissions (lb SO ₂ /10 ⁶ Btu)
> 12	> 90	1.2 maximum
12 to 6	90	1.2 → 0.6
6 to 2	90 → 70	0.6 (constant)
< 2	70	< 0.6

Basically, for steam coals burned by utilities with uncontrolled emissions exceeding 12 lb SO₂/10⁶ Btu, SO₂ reductions exceeding 90 percent would be required to limit emissions to a maximum of 1.2 lb SO₂/10⁶ Btu. For those coals whose uncontrolled emissions would range from 12 to 6 lb/10⁶ Btu, a constant 90-percent removal is required, resulting in controlled emissions ranging from 1.2 lb SO₂/10⁶ Btu to 0.6 lb/10⁶ Btu. For coals with sulfur contents that would emit 6 to 2 lb SO₂/10⁶ Btu, a variable removal rate between 90 and 70 percent is required to achieve a constant 0.6 lb SO₂/10⁶ Btu. For example, at 6 lb SO₂/10⁶ Btu, 90-percent removal is required; at

2 lb SO₂/10⁶ Btu, 70 percent is required; and at 3 lb SO₂/10⁶ Btu, 80 percent is needed. In all cases, it should be noted that the controlled emissions are 0.6 lb/10⁶ Btu. If the uncontrolled emissions are less than 2 lb/10⁶ Btu, 70 percent SO₂ is then required.

On a yearly basis, controlling SO_x and NO_x to 0.6 lb/10⁶ Btu gives (at 80-percent capacity factor),

$$\begin{aligned} \text{SO}_x \text{ (and NO}_x\text{)} &= (0.6 \text{ lb}/10^6 \text{ Btu})(34 \times 10^{12} \text{ Btu/yr}) \\ &= 20.4 \times 10^6 \text{ lb/yr} \\ &= 10.2 \times 10^3 \text{ tons/yr} \end{aligned}$$

The SO₂ removal requirements for a 12,000 Btu/lb coal are illustrated in Figure 2. Seventy percent SO₂ removal is required up to a sulfur content of 1.2 percent. Between 3.6 and 7.2 percent, 90-percent removal is required. If the sulfur content is in the range between 1.2 and 3.6, different removal rates, as shown, are required to maintain the 0.6 lb SO₂/10⁶ allowable. For the coal used in this ECIR (3.3 percent sulfur and 12,000 Btu/lb), an overall 89.1-percent SO₂ removal is needed. With a total of 10 percent sulfur removed as a result of pyrite removal in the coal pulverizer and as sulfur retained in the bottom ash and fly ash, the sulfur content as seen by the scrubber is 3.0 percent (3.3 - 0.1 x 3.3). The scrubber will therefore be required to remove 88 percent to achieve the overall 89.1-percent reduction.

FIGURE 2. OVERALL SO₂ REDUCTION REQUIRED FOR A 12,000 Btu/lb COAL TO MEET CURRENT NSPS REGULATIONS

NO_x

The current New Source Performance Standard for NO_x regulations is¹ 0.6 lb/10⁶ Btu.

The amount of NO_x emitted to the ambient atmosphere is 0.6 lb/10⁶ Btu. The general way of achieving compliance with NO_x emissions is to employ combustion modification techniques.^{2,4} The boiler manufacturer usually includes in his performance guarantee the provision that emissions of nitrogen oxides while firing coal shall be less than 0.6 lb/10⁶ Btu.³ Emissions of oxides of nitrogen are limited by low flame and furnace temperatures, by short residence time of the gases at high temperatures, and by reduced amounts of excess air present in the flame.

Particulates

The current New Source Performance Standard for particulate regulation is 0.03 lb/10⁶ Btu.

The amount of particulates (i.e., fly ash that is not captured in the electrostatic precipitator) emitted to the ambient atmosphere is 0.03 lb/10⁶ Btu. The amount of ash in the coal used in this ECIR is 8.8 percent. If 80 percent of the ash is emitted as fly ash and the electrostatic precipitator efficiency is 99.5 percent, the particulate emission to the atmosphere is given by

$$\text{Particulates} = (\text{ash fraction in coal})(\text{fly ash fraction})(\text{coal feed rate}) \\ (1 - \text{electrostatic precipitator efficiency})$$

For the typical plant,

$$\text{Particulates} = (0.088)(0.80)(4.9 \times 10^3 \text{ tons/day})(1 - 0.995) \\ = 1.7 \text{ tons/day}$$

On a yearly basis,

$$\text{Particulates} = (1.7 \text{ tons/day})(0.8 \text{ capacity factor})(365 \text{ days/yr}) \\ = 500 \text{ tons/yr}$$

On a yearly basis, controlling particulates (TSP) to 0.03 lb/10⁶ Btu gives (at 80-percent capacity factor),

$$\text{TSP} = (0.03 \text{ lb/10}^6 \text{ Btu})(34 \times 10^{12} \text{ Btu/yr}) \\ = 1.02 \times 10^6 \text{ lb/yr} \\ = 500 \text{ tons/yr}$$

Carbon Monoxide and Hydrocarbons

There are no New Source Performance Standards for carbon monoxide (CO) or hydrocarbons (HC). The amounts of CO and HC emitted to the ambient atmosphere are 2.45 tons/day and 0.74 ton/day, respectively. The emission factors for CO and HC are 1 lb/ton coal burned and 0.3 lb/ton coal burned, respectively.⁵ Hence, the daily emissions of these pollutants are given by

$$\text{CO, HC} = (\text{emission factor})(\text{coal feed rate})$$

For the typical plant,

$$\begin{aligned}\text{CO} &= (1 \text{ lb/ton})(4.9 \times 10^3 \text{ tons/day})/2 \times 10^3 \text{ lb/ton} \\ &= 2.45 \text{ tons/day}\end{aligned}$$

$$\begin{aligned}\text{HC} &= (0.3 \text{ lb/ton})(4.9 \times 10^3 \text{ tons/day})/2 \times 10^3 \text{ lb/ton} \\ &= 0.74 \text{ ton/day}\end{aligned}$$

On a yearly basis,

$$\begin{aligned}\text{CO} &= (2.45 \text{ tons/day})(0.8 \text{ capacity factor})(365 \text{ days/yr}) \\ &= 720 \text{ tons/yr}\end{aligned}$$

$$\begin{aligned}\text{HC} &= (0.74 \text{ tons/yr})(0.8 \text{ capacity factor})(365 \text{ days/yr}) \\ &= 220 \text{ tons/yr}\end{aligned}$$

An indication of the completeness of a combustion process is the concentration of carbon monoxide (and, to a lesser extent, hydrocarbon concentration). As such, pulverized coal-fired boilers have negligible emissions of carbon monoxide and hydrocarbons. Careful monitoring of excess air and temperature in the boiler ensures that the emissions of these pollutants are low.⁶

Trace Elements

Atmospheric emission rates for the trace elements are calculated as follows (Appendix C):

<u>Element</u>	<u>lb/day at 100% capacity factor</u>	<u>lb/yr at 80% capacity factor</u>
As	0.77	225
Be	0.03	9.3
Cd	0.01	4.1
Mn	0.55	161
Pb	0.39	114
Se	0.19	56

The trace elements are species found in small quantities in the raw coal. They become distributed among the bottom ash slag or the fly ash and flue gases. In the latter, some are emitted past the precipitator and enter the atmosphere. Because many trace elements exhibit preferential concentrations in the smaller particles emitted, about 5 percent of the initial concentrations of most trace elements are emitted to the ambient atmosphere.⁷ Based on recent work at Lawrence Livermore Laboratory, a method was developed to calculate trace element emissions to the atmosphere. The generalized methodology, algorithm, and associated references for calculating trace element emissions are given in Appendix B.

Carbon Dioxide

The amount of CO₂ emitted to the ambient atmosphere is 12.5×10^3 tons/day. During the combustion of bituminous coal, 0.21 lb CO₂ are emitted to the atmosphere for every 10³ Btu generated.⁸ Hence,

$$(CO_2)_{COMB} = (\text{emission factor})(\text{coal feed rate})(\text{heat content of coal})$$

For the typical plant,

$$\begin{aligned}(CO_2)_{COMB} &= (0.21 \text{ lb}/10^3 \text{ Btu})(4.9 \times 10^3 \text{ tons/day})(12 \times 10^3 \text{ Btu}/\text{lb}) \\ &= 12.3 \times 10^3 \text{ tons/day}\end{aligned}$$

Additionally, a small amount of CO₂ is released to the atmosphere from the limestone reaction with the SO₂.⁹ This amount is estimated as follows:

$$\begin{aligned}(CO_2)_{LIMESTONE} &= \left(\frac{500 \text{ tons/day, limestone into}}{\text{scrubber}} \right) \left(\frac{44}{100} \cdot \frac{\text{molecular weight}}{\text{of SO}_2/\text{CaCO}_3} \right) \\ &= 0.220 \times 10^3 \text{ tons/day}\end{aligned}$$

The total amount of CO₂ emitted to the atmosphere is given by

$$\begin{aligned}CO_2 &= (CO_2)_{COMB} + (CO_2)_{LIMESTONE} \\ &= 12.3 \times 10^3 \text{ tons/day} + 0.22 \times 10^3 \text{ tons/day} \\ &= 12.5 \times 10^3 \text{ tons/day}\end{aligned}$$

On a yearly basis,

$$\begin{aligned}CO_2 &= (12.5 \times 10^3 \text{ tons/day})(0.8 \text{ capacity factor})(365 \text{ days/yr}) \\ &= 3.7 \times 10^6 \text{ tons/yr}\end{aligned}$$

Radionuclides

Analysis of the fly ash produced by combustion of eastern bituminous coal has shown that a typical 500-MWe plant will discharge into the atmosphere approximately 10.35×10^{-6} Ci/day of radioactive radium.

Because over 80 percent of the trace radioactive particles in coal remain with the fly ash after combustion, removal of the fly ash by electrostatic precipitators is the most effective control technology available.¹⁰ Samples from the combustion of six different batches of Appalachian coal were analyzed for its radium content by Eisenbud and Petrow with the following results:¹⁰

Concentration of Radioactive Elements in Fly Ash

Radium-226	3.8×10^{-12} Ci/gm	or	1.73×10^{-9} Ci/lb
Radium-228	2.4×10^{-12} Ci/gm		1.09×10^{-9} Ci/lb

Other trace radioactive elements are emitted, e.g., thorium and uranium, but pose a much smaller health hazard than radium.

Assuming the total activity released to the environment is through the fly ash escaping the electrostatic precipitators, the daily release of any radioactive isotope may be calculated as follows:

$$\text{Activity of isotope } i, \text{ Ci/day} = (\text{concentration of isotope } i \text{ in fly ash}) \\ (\text{fly ash generated, tons/day})(2000 \text{ lbs/ton}) \\ (1 - \text{ESP EFFICIENCY})$$

For the typical plant,

$$\begin{aligned} \text{Radium-226} &= (1.73 \times 10^{-9} \text{ Ci/lb})(367 \text{ tons/day})(2000 \text{ lbs/ton})(1 - .995) \\ &= 6.35 \times 10^{-6} \text{ Ci/day} \\ \text{Radium-228} &= (1.09 \times 10^{-9} \text{ Ci/lb})(367 \text{ tons/day})(2000 \text{ lbs/ton})(1 - .995) \\ &= 4.00 \times 10^{-6} \text{ Ci/day} \end{aligned}$$

Total radium activity emitted daily for the typical plant is therefore 10.35×10^{-6} Ci/day.

On a yearly basis,

$$\begin{aligned} \text{Radium} &= (10.35 \times 10^{-6} \text{ Ci/day})(0.8 \text{ capacity factor})(365 \text{ days/yr}) \\ &= 3 \times 10^{-3} \text{ Ci/yr} \end{aligned}$$

To date, there are no regulations that apply to the release of radioactive pollutants from coal-fired power plants.

References

1. Federal Register, Vol. 44, No. 113, 40 CFR Part 60, "New Sources Performance Standards; Electric Utility Steam Generating Units," June 11, 1979.

2. J. Ando, "NO_x Abatement for Stationary Sources in Japan," EPA-600/7-79-205, August 1979.
3. U.S. Environmental Protection Agency, "Electric Utility Steam Generating Units: Background Information for Proposed NO_x Emission Standards," EPA-450/2-78-005a, July 1978.
4. National Academy of Sciences, "Air Quality and Stationary Source Emission Control," prepared for the Committee on Public Works, U.S. Senate, Serial No. 94-4, 1975.
5. U.S. Environmental Protection Agency, "Compilation of Air Pollution Emission Factors," 2nd edition, EPA AP-42, 1975.
6. Final Environmental Impact Statement, Spurlock Station, Unit No. 2 and Associated Transmission, USDA-REA-EIS-76-4F, November 1976.
7. K.K. Bertin and E.D. Goldberg, Science, Vol. 183, p. 233, 1971.
8. U.S. Department of Energy, "CO₂ Emissions from Synthetic Fuels Energy Sources," August 8, 1979, p. 2, Table 1.
9. Aerospace Corporation, Estimation, April 1980.
10. M. Eisenbud and H.G. Petrow, "Radioactivity in the Atmospheric Effluents of Power Plants That Use Fossil Fuels," Science 144, April 17, 1964, p. 288

III. PHYSICAL REQUIREMENTS

Large amounts of land and water resources are required for a coal-fired power plant. The section on Water summarizes the requirements and uses of makeup water discussed in Section II. The section on Land discusses the land needed for plant siting and solid waste disposal.

Water

The maximum makeup water requirement estimated for the typical plant operating at 80-percent capacity factor is 2.7×10^9 gal/yr. Some of this water is recovered, treated in the water treatment facility, and recycled back to the plant (see Section II, item (16)). The remainder is obtained from local water sources and is lost primarily through evaporation and drift losses in the cooling towers, holding pond surface losses, and dust suppression systems. The major uses of makeup water are listed in Table 2.

Land

The sizes of actual power plant sites vary over a considerable range and depend on a number of factors such as utility preference, cost of land, onsite versus offsite waste disposal, plant location, and the power of the plant. Although there is not a strong link between site size and the particular features of the plant (such as MWe), broad relationships exist. For plants in the 500-MWe range, site sizes appear to vary from about 500 to 1000 acres. There are a number of older plants sited in urban areas with much smaller sites, but they should not be considered typical for new plants.

Because the land needed for buildings is a relatively small portion of the site, the bulk of the site is needed for coal storage, onsite waste disposal (ponds, etc.), and general working room. Solid waste disposal area for a plant similar to the typical plant was estimated at 370 acres (30-foot depth) for the 30-year lifetime of the plant (see Section II, item (29)).¹ A representative 500-MWe plant that does not have onsite solid waste disposal for the entire life of the plant has a site size of approximately 400 acres, excluding waste disposal.² Accordingly, 800 acres is a typical site size when lifetime waste disposal is included.

The typical plant was designed as a mine-mouth plant with its own coal preparation plant. The actual coal preparation facilities would require a minimum of 1.5 acres.³ In addition, if the refuse from the preparatory plant is kept aboveground, disposal area will be required. The preparatory plant will generate 1800 tons/day of refuse (see Section II, item (4) for

**Table 2. Makeup Water Demands for Major Plant Processes
(at 80-Percent Capacity Factor)**

<u>Source</u>	<u>Environmental Point of Interest on Flow Chart</u>	<u>Estimated Quantity (gal/yr)</u>
Cooling tower makeup	11	2.2×10^9
SO _x control	21	300×10^6
Generating plant makeup	13	180×10^6
Electrostatic precipitator fly ash transport	18	24×10^6
Total estimated makeup water demand	-	$\approx 2.7 \times 10^9$
<u>Recovered Water for Recycling</u>		
Controlled runoff from coal storage	7	Variable
Boiler blowdown and miscellaneous plant drains	12	175×10^6
Cooling tower blowdown	10	200×10^6
Water removed from solid waste handling system	20	Variable
Total estimated recycled water available for makeup	16	$\approx 29 \times 10^6$
Net makeup water requirements	-	2.67×10^9
 Total estimated makeup water demand	-	2.7×10^9
Total estimated avail- ability of recycled water	-	29×10^6

calculation). Assuming a density of 50 lb/ft³, and a 30-foot depth, the land requirements for waste disposal are calculated as follows:

$$\text{Land requirements, acres/yr} = \frac{0.34 (\text{solid waste disposal, tons/day})}{\text{depth of disposal site, ft}}$$

For the typical plant,

$$\begin{aligned} \text{Land} &= \frac{0.34 (1800 \text{ tons/day})}{30 \text{ ft}} \\ &= 20.4 \text{ acres/yr (at 100-percent capacity factor)} \\ &= (20.4)(0.8) \\ &= 16 \text{ acres/yr (at 80-percent capacity factor)} \end{aligned}$$

For the 30-year lifetime of the plant, the land required for coal preparation waste disposal is therefore approximately 500 acres.

References

1. U.S. Environmental Protection Agency, "Electric Utility Steam Generating Units: Background Information for Proposed SO₂ Emission Standards," EPA-450/2-78-007a, pp. 6-18, July 1978.
2. Final Environmental Impact Statement, Spurlock Station Unit No. 2, and Associated Transmission, USDA-REA-EIS-76-4F, November 1976, p. 69.
3. Personal Communication, Phillip Halch, Roberts and Schaefer Engineers and Contractors, April 1980.

IV. PERSONNEL

Although the number of people required for the operation and planned maintenance of a power plant is highly dependent on the philosophy of the particular utility, certain standards are used. One such guideline is 0.089 persons/MWe for each shift.¹ This number, which includes support personnel and personnel for operating and maintaining pollution control equipment, equates to 45 persons per shift or 135 persons total per day for a 500-MWe plant.

In addition to the above requirement, personnel will be needed for the coal preparation plant. Although preparation plant staffing levels vary, discussions with power engineers revealed that 10 persons per shift or 20 persons total for the two preparation plant shifts would be a reasonable figure.

Reference

1. Personal Communication, John W. Holt, Jr., Power Plants Branch, Rural Electrification Administration, Washington, D.C., April 1980.

V. OCCUPATIONAL SAFETY AND HEALTH

Occupational safety and health implications of coal-fired power plants have been examined using actual death and injury statistics.¹ For coal processing plants, the report lists (per 10^8 tons processed) 1.7 to 2.7 deaths and 98 to 159 injuries. The corresponding figures for power plant workers (per 10^{12} Btu output) are 0 to 0.0095 deaths and 0.16 to 0.19 injuries.

For the plant assumed in this ECIR, the amount of coal processed is 1.96×10^6 tons/yr and 0.16×10^6 tons/ 10^{12} Btu. The output of the plant is 1×10^{12} Btu/yr. Thus, the projected deaths and injuries for the plant are as follows:

	<u>Preparation Plant</u>		<u>Power Plant</u>	
	<u>Annual</u>	<u>Per 10^{12} Btu</u>	<u>Annual</u>	<u>Per 10^{12} Btu</u>
Deaths	0.0033-0.0053	0.0003-0.0004	0-0.11	0-0.0095
Injuries	1.9-3.1	0.16-0.26	1.9-2.3	0.16-0.19

Reference

1. S.C. Morris, K.M. Novak, and L.D. Hamilton, "Health Effects of Coal in the National Energy Plan," Brookhaven National Laboratory, BNL-51043, April 1979, pp. 8-9.

APPENDIX A. AIR EMISSIONS UNDER VARIOUS REGULATORY AND CONTROL TECHNOLOGY ASSUMPTIONS

The air emissions calculated for the coal-fired power plant described in this document are based on current Federal NSPS for coal-fired power plants using bituminous coal and that commenced construction after September 18, 1978. The units coming on line now and for several years into the future are generally subject to the previous Federal NSPS. There are also many units now operating that were under construction or operating prior to the effective date of the previous NSPS and are therefore not subject to any Federal NSPS. Although these plants are subject to Federal NSPS less stringent than the current regulation, they will in many instances be subject to more stringent state and local air emission regulations. In many instances, the new plants, subject to current Federal NSPS, will also be subject to more stringent state or local standards that will effectively establish the allowable air pollutant emission levels. Table A-1 provides a summary of air emissions under current NSPS and previous NSPS, as well as emissions from uncontrolled plants.

It should also be noted that under the previous NSPS and uncontrolled assumptions, coals having low-sulfur content could be used to reduce SO₂ emissions and to thus comply with the NSPS standard. The new NSPS do not allow the use of low-sulfur coal alone as an SO₂ control for new plants.

In addition to impacts on air emissions, the use of a limestone or lime scrubber generates a varying amount of solid waste (scrubber sludge). As SO₂ removal requirements increase, the amount of scrubber sludge will increase (see item (9), Sludge From SO₂ Control). Solid wastes will also be increased if a higher ash coal is selected (see item (17), Fly Ash From Particulate Control).

Table A-1. Air Emissions Under Various Regulatory Assumptions*

Federal Regulation	Firing Rate - 34 x 10 ¹² Btu/yr		
	SO ₂	NO _x	Particulate
Current NSPS As of 6/11/79	.6 lb/10 ⁶ Btu 10.2 x 10 ³ tons/yr	.6 lb/10 ⁶ Btu 10.2 x 10 ³ tons/yr	.03 lb/10 ⁶ Btu .50 x 10 ³ tons/yr
Previous NSPS 12/23/71 to 6/11/79	1.2 lb/10 ⁶ Btu 20.4 x 10 ³ tons/yr	.7 lb/10 ⁶ Btu 11.9 x 10 ³ tons/yr	.1 lb/10 ⁶ Btu 1.7 x 10 ³ tons/yr
Uncontrolled emissions	85 x 10 ³ tons/yr	**"Normal firing" @ .82 lb/10 ⁶ Btu 13.9 x 10 ³ tons/yr	50% mechanical removal of fly ash 50 x 10 ³ tons/yr

* Based on the plant assumed in this ECIR, using a coal with 3.3 percent sulfur content.

** U.S. Environmental Protection Agency, "Electric Utility Steam Generating Units: Background Information for Proposed NO_x Emission Standards," EPA-450/2-78-005a, July 1978, p. 6-9.

APPENDIX B. COST INFORMATION

Obtaining an accurate estimate of the costs associated with any power plant is an ambitious undertaking and beyond the scope of this study. However, sufficient information is available to approximate the costs for the typical plant.

An extensive effort by the Department of Energy (DOE) and the Nuclear Regulatory Commission (NRC)¹ examined the total costs (capital, fuel, and operating and maintenance) for various plant types and sizes under a range of economic assumptions. The plant most similar to the typical plant in Environmental Characterization Information Report (ECIR) is a 794-MWe plant burning high-sulfur coal. It, too, is a pulverized coal plant with electrostatic precipitator and flue gas scrubbers.

There is sufficient information in the study to determine approximate economies of scale with respect to plant size. When the data for the 794-MWe plant are converted to our 500-MWe plant size, the result for plant capital cost is \$450/kW (1976 dollars) or \$225,000,000. The DOE/NRC study provided an analysis that assumed an 8-percent escalation rate and a 1985 date for first operation. Under these assumptions, correcting for escalation, interest during construction, and contingency, the total (integrated) capital cost for the 500-MWe plant is \$1270/kW, or \$635,000,000. If the escalation rate were only 5 percent, the capital cost would be \$1030/kW, or \$514,000,000.

The study also calculated the total costs for the 1985 plant in mills/kWh (including capital, fuel, and operating and maintenance), assuming 8-percent escalation and a 12-percent discount rate, as well as the alternate economic assumptions of 5-percent escalation and 10-percent discount rate. As might be expected, this total cost will depend on the portion of time the plant actually operates (capacity factor). The total costs for the 500-MWe plant are as follows:

Capacity Factor (%)	Total Generating Costs (mills/kWh)	
	8% Escalation 12% Discount	5% Escalation 10% Discount
50	116.9	87.4
60	107.4	78.8
70	101.1	72.8
80	96.0	68.1

These cost figures include transportation of coal 900 miles from the eastern high-sulfur coal mines to a hypothetical northeastern coastal location. If coal transportation were not necessary, as in the case of the mine-mouth typical plant, the total generating costs would be reduced by 23.6 mills/kWh for the 8-percent escalation/12-percent discount case and 13.8 mills/kWh for the 5-percent escalation/10-percent discount case. Thus, the costs for the typical plant, excluding coal preparation, are as follows:

Capacity Factor (%)	Total Generating Costs (mills/kWh)	
	8% Escalation	5% Escalation
	12% Discount	10% Discount
50	93.3	73.6
60	83.8	65.0
70	77.5	59.0
80	72.4	54.3

The capital cost for the coal preparation plant is estimated at \$10.5 million in 1976 dollars, with operating and maintenance costs of \$1.33/ton of coal.² This total cost for the coal preparation plant, which is not very sensitive to the capacity factor, is 5.8 mills/kWh for the 8-percent escalation/12-percent discount case and 3.9 mills/kWh for the 5-percent escalation and 10-percent discount case.

References

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APPENDIX C. TRACE ELEMENT ANALYSIS

Trace elements are species that are found in small quantities in a mineral. During coal combustion, they become distributed among slag, fly ash, or gases and are emitted into the environment. Based on industrial experience with pulverized coal boilers, it is generally accepted that 80 percent of the ash present in coal is charged as fly ash, while only 20 percent is discharged as bottom ash.^{1,2} Because many trace elements exhibit preferential concentrations in the smaller particles emitted from coal-fired power plants,^{3,6} about 5 percent of the initial concentrations of most trace elements are emitted to the ambient atmosphere.⁷ In addition, due to the nonhomogeneity of coal, the composition and concentration of combustion products will vary with coal. However, based on recent work conducted by Lawrence Livermore Laboratory, it is possible to calculate trace element emissions if certain system operating parameters and coal composition are known.⁸ An explanation of how this is done follows.*

Needed information:

- Trace element concentrations in coal being fired (C_i , $i=1, 2, \dots, n$, $\mu\text{g/g}$)
- Coal feed rate (F , g/sec)
- Plant net power output (P , watts)
- Overall thermal efficiency (η_p)
- Electrostatic precipitator overall efficiency (η_{ESP})

Definitions:

plant total power input = (plant net power output)/(overall thermal efficiency)

$$= P/\eta_p$$

(consumption rate) $_i$ = (trace element i concentration in coal) (coal feed rate)/(plant total power input)**

$$= (C_i)(F)/P/\eta_p$$

ESP efficiency ratio = (1-ESP overall efficiency)/(1-ESP overall efficiency used in LLL study)

$$= (1-\eta_{\text{ESP}})/(1-0.97)$$

* There are other methodologies for determining trace element emissions; see, for example, Reference 9.

** Note: 1 watt = 1 joule/second.

(atmospheric emission rate)_i = (stack emission of trace element i)/(plant total power input)

(AER)_i = unknown to be determined

(penetration)_i = (100%) (atmospheric emission rate)_i/(consumption rate)_i

= given in following Table C-1

Procedure:

1. When the needed information is obtained, determine
 - plant total power input
 - (consumption rate)_i
 - ESP efficiency ratio
2. Obtain (penetration)_i from Table C-1
3. (atmospheric emission rate)_i = (penetration)_i(consumption rate)_i (ESP efficiency ratio)/100

$$(AER, \mu g/joule)_i = (penetration)_i \{ (C_i)(F)/(P/\eta_p), \mu g/joule \} (1-\eta_{ESP})/((1-0.97))$$

For the typical plant a representative coal from Kentucky was chosen.¹⁰ Trace element concentrations of this coal are listed as follows:

Element	Concentration ($\mu g/g$)
As	4.1
Be	2.2
Cd	0.1
Mn	21.0
Pb	4.3
Se	1.5

To find the atmospheric emission rates for the trace elements, the following information is used:

P = 5×10^8 watt
 η_p = 35 percent
 F = 5.15×10^4 g/sec
 η_{ESP} = 99.5 percent

Table C-1. Penetration of Elements Contained in Particles Emitted From an ESP-Equipped Coal-Fired Generating Unit (%)

Element	ESP Unit ^a	Element	ESP Unit ^a
Al	1.1 ± 0.1	Mo	5.1 ± 1.2
As	11.5 ± 3.0	Mn	1.6 ± 0.5
Ba	4.0 ± 0.8	Na	1.55 ± 0.09
Be	0.9 ± 0.3	Pb	5.5 ± 1.1
Br	0.14 ± 0.08	Rb	1.3 ± 0.1
Ca	1.3 ± 0.2	Sb	7.7 ± 0.7
Cd	8.8 ± 3.0	Sc	1.46 ± 0.06
Ce	1.29 ± 0.09	Se	7.7 ± 0.8
Co	2.5 ± 0.3	Sr	2.0 ± 0.3
Cr	3.8 ± 0.3	Ta	1.3 ± 0.1
Cs	1.2 ± 0.2	Th	1.32 ± 0.08
Fe	1.32 ± 0.09	Ti	1.51 ± 0.03
Ga	4.4 ± 0.7	U	3.7 ± 0.4
In	5.4 ± 0.7	V	3.7 ± 0.6
K	1.0 ± 0.3	W	7.2 ± 2.2
La	1.29 ± 0.07	Zn	6.3 ± 0.8
Mg	1.2 ± 0.4	Zr	1.4 ± 0.3

^a Number of samples was eight unless otherwise indicated.

The atmospheric emission rate for arsenic is therefore

$$\begin{aligned}
 (AER)_{As} &= \left[\frac{(\text{penetration})_{As} (C_{As})(F)}{(P/n_p)} \right] \left[\frac{1-ESP}{1-0.97} \right] \\
 &= \left[\frac{(0.115)(4.1 \mu\text{g/g})(5.15 \times 10^4 \text{ g/s})}{5 \times 10^8 \text{ J/s} / 0.35} \right] \left[\frac{1-0.995}{1-0.97} \right] \\
 &= 2.83 \times 10^{-6} \mu\text{g/J}
 \end{aligned}$$

On a daily basis,

$$\begin{aligned}
 (AER)_{As} &= \frac{(2.83 \times 10^{-6} \mu\text{g/J})(1.055 \times 10^3 \text{ J/Btu})(0.117 \times 10^{12} \text{ Btu/day})(1 \times 10^{-6} \text{ g}/\mu\text{g})}{(4.54 \times 10^2 \text{ g/lb})} \\
 &= 0.77 \text{ lb/day}
 \end{aligned}$$

Daily atmospheric emission rates for the trace elements are as follows:

<u>Element</u>	<u>lb/day at 100% capacity factor</u>	<u>lb/yr at 80% capacity factor</u>
As	0.77	225
Be	0.03	9.3
Cd	0.01	4.1
Mn	0.55	161
Pb	0.39	114
Se	0.19	56

References

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8. J.M. Ondov, R.C. Ragaini, and A.H. Biermann, "Emissions and Particle-Size Distributions of Minor and Trace Elements at Two Western Coal-Fired Power Plants Equipped with Cold-Side Electrostatic Precipitators," Environmental Science and Technology, Vol. 13, pp. 946-953, 1979.
- Radian Corporation, "Trace Elements of Fly Ash: Emissions from Coal Fired Steam Plants Equipped with Hotside and Coldsides Electrostatic Precipitators for Particulate Control," EPA 908/4-78-008, December 1978, Final Report.
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GLOSSARY

Blowdown	Water that is periodically removed from either the cooling towers or the coal-fired boiler to prevent concentration of total dissolved solids.
Bottom ash	Noncombustible residues of coal combustion that are collected and removed from the boiler.
Capacity factor	The actual plant output in a year divided by the output that would be achieved if the plant were to operate at 100-percent power for 365 days/year.
Circulating water	Water supplied to the main condenser in the generating plant that is cooled by the cooling towers.
Cooling tower drift loss	Aerosols of water that are lost in the atmosphere from the cooling towers.
Cooling tower evaporation loss	Circulating water that is evaporated as a result of heat transferred from the circulating water system and lost in the atmosphere via the cooling towers.
Dead storage	Long-term storage in which the coal is typically compacted and sealed.
Discount rate	A factor in formulas used for analyzing the time value of money. Its magnitude depends on the cost of capital, financing schemes, etc.
Electrostatic precipitator	Environmental control device used to remove a high percentage of the fly ash in the flue gas.
Escalation	Increases in cost of equipment, materials, labor, etc., as a result of inflation.
Flue gas	Gases generated from the combustion of fossil fuel in the boiler.
Flue gas desulfurization scrubbers	Environmental control device used to remove a high percentage of the sulfur dioxide in the flue gas.
Fly ash	Noncombustible residues of coal combustion that are carried out of the boiler in the flue gas.
Fugitive emissions	Unintentional emissions, such as blowing dust from a coal pile.

Net station heat rate (Q)	Amount of fuel input (in Btu) necessary to generate 1 kWh of electricity.
Pyritic material	Metallic compounds of sulfur naturally occurring in coal.
Recycle water	Water that is collected, treated, and reused at the power plant.
Run-of-mine coal	Coal as it comes from the mine prior to sizing or other preparation.
Sludge	Wet residue of lime/limestone and sulfur that is generated in the flue gas desulfurization unit.

ACRONYMS AND ABBREVIATIONS

A	ash content in coal
AER _i	atmospheric emission rate of trace element i
As	arsenic
Be	beryllium
Btu	British thermal unit
C	carbon
CaSO ₃	limestone
Cd	cadmium
Ci	curie
C _i	concentration of trace element i
Cl	chlorine
CO	carbon monoxide
CO ₂	carbon dioxide
Cu	copper
DOE	Department of Energy
ECIR	Environmental Characterization Information Report
η _p	overall thermal efficiency of plant
η _{ESP}	overall efficiency of electrostatic precipitator
EPA	Environmental Protection Agency
ESP	electrostatic precipitator
F	feed rate of coal
Fe	iron
FGD	flue gas desulfurization
g	gram
gal	gallon
H	hydrogen
ha	hectare
HC	hydrocarbons
J	joule
kg	kilogram
kWh	kilowatt-hour
l	liter
lb	pound
mg	milligram (10 ⁻³ gram)
μg	micrograms (10 ⁻⁶ grams)
Mn	manganese
MWe	megawatt - electrical
MWt	megawatt - thermal
NO _x	nitrogen oxides
NRC	Nuclear Regulatory Commission
NSPS	New Source Performance Standards
O	oxygen
P	net power delivered to the transmission grid
Pb	lead
Q	heat content of coal
Q	net station heat rate
ROM	run-of-mine

s	second
S	sulfur
Se	selenium
SO ₂	sulfur dioxide
te	tonne
TSP	total suspended particulates (air)
TSS	total suspended solids (water)
WBA	total makeup water requirements for bottom ash handling
WBLowDOWN	amount of cooling tower blowdown
WDRIFT	amount of drift loss from cooling tower
WEVAP	amount of evaporation loss from cooling tower
WFGD	makeup water for dust control of SO ₂ scrubbers
WHAD	amount of water needed for bottom ash handling and disposal
WTOW	total makeup water requirements to the cooling towers
WVAP	amount of evaporation loss from bottom ash hopper