C

Center for Advanced Computation

UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
URBANA, ILLINOIS 61801

CAC Document No. 165

TOTAL ENERGY REQUIREMENTS FOR NINE ELECTRICITY-GENERATING SYSTEMS

by

David A. Pilati
Ralph P. Richard

August 1975

CAC DOCUMENT NO. 165

TOTAL ENERGY REQUIREMENTS FOR NINE ELECTRICITY-GENERATING SYSTEMS

By

David A. Pilati

Ralph P. Richard

Center for Advanced Computation
University of Illinois at Urbana-Champaign
Urbana, Illinois 61801

August 1975

ABSTRACT

Using the CAC energy-employment policy model, a methodology is developed to compute the total energy requirements for complete energy supply systems. The capital and operating requirements of 16 separate energy supply facilities are used to evaluate the total energy required by nine alternative means of producing and delivering electricity. The evaluated electricity-generating systems rely on either coal, oil, natural gas, or nuclear energy as their fuel source. Each system is a net energy sink for some time after operation commences. However, in less than two-thirds of a year each system produces more electricity than would have been produced if the energy requirements (other than fuel) had been diverted to existing electricity-generating systems. Lack of data precluded the inclusion of all transportation-related requirements. Energy payback periods could be more than doubled if these requirements were included.

TABLE OF CONTENTS

Page

Appendix:

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGMENTS

The authors are greatly indebted for the guidance and suggestions offered by Professor Clark Bullard. They would also like to thank Nadine Abbott for computer programming assistance and Veronica Soltys for typing assistance.

1. INTRODUCTION

Energy is required to produce the goods and services that society consumes. This somewhat trite statement has been the subject of several detailed analyses that quantified these requirements for a variety of products.[1-4] Energy conversion systems also require energy to build, operate, and be disposed of at the end of their useful lifetime. This fact has led to questioning whether a particular energy conversion system is energy profitable.

Using a truncated process analysis, Chapman and Mortimer investigated a variety of nuclear-electricity systems for their total energy costs.[5] They found these systems to be energy profitable for present uranium ore concentrations. However, these systems are quite capital-intensive and high growth rates in constructing them can delay their energy payback for many years. Furthermore, the energy requirements for mining low-grade uranium ores could result in nuclear power becoming an energy sink in the future.

This report develops a methodology for calculating the total energy requirements of complete energy supply systems. Using a number of data sources for individual energy facilities, this procedure is applied to examine the total energy required to construct and operate nine electricity-generating systems. Each system converts one of four energy resources (coal, crude oil, natural gas or nuclear) into electricity. Table 1 lists the systems investigated.

Each system consists of a set of individual facilities which mine, process and convert a basic energy resource into electricity. A total of 16 facilities are required for the nine systems examined. These

Table 1

Electricity-Generating Systems

Resource Base	System ID	System Definition
Coal	CM-CFPP	Coal Mine → Coal Fired-Power Plant
	CM-CG-NGU-GFPP	Coal Mine → Coal Gasification → Natural Gas Utility → Gas-Fired Power Plant
	CM-CCC	Coal Mine → Coal Combined Cycle Power Plant
	CM-SRC-CFPP	Coal Mine → Solvent Refined Coal → Coal-Fired Power Plant
Natural Gas	GP-NGU-GFPP	Gas Production → Natural Gas Utility → Gas-Fired Power Plant
Crude Oil	CO-LGR-OFPP	Crude Oil Production → Low Gas Refinery → Oil-Fired Power Plant
	SO-LGR-OFPP	Oil Shale Mine/Retort → Low Gas Refinery → Oil-Fired Power Plant
Nuclear	LWR	LWR Fuel Mining/Processing → LWR Power Plant
	HTGR	HTGR Fuel Mining/Processing → HTGR Power Plant

facilities include both existing technologies (such as a coal-fired power plant) and new technologies (such as the coal combined-cycle consisting of a low Btu gasification plant and a gas turbine topping cycle power plant).

The total energy necessary to construct and operate these systems can be divided into direct and indirect requirements. Direct energy requirements include the coal to fuel a coal-fired power plant or the diesel fuel needed for a power plant's auxiliary power system. Indirect energy use results from the energy embodied (due to manufacturing requirements, transportation, etc.) in the material requirements of the system. Quantification of the indirect energy needs is effected by the CAC energy-employment model.[6] This model is an extension of economic input-output analysis.

The analysis in this report includes only the first two relevant time periods for energy supply systems: construction and operation. Each system is an energy sink during construction, characterized by large indirect energy requirements to manufacture its capital equipment and a smaller amount of direct energy requirements for the system's construction. Once operational, a system becomes an electricity source while consuming large amounts of its resource base in a direct manner. In general, the indirect requirements during operation are less than during the construction phase. Data limitations and conceptual questions concerning appropriate discount rates have precluded consideration of the energy costs of system decommissioning or the safeguarding of nuclear wastes.

The next section of this report outlines the methodology used in the energy analysis of the sixteen separate facilities. Also included is a description of how these facility requirements are combined to give the energy requirements to build and operate an entire electricity-generating system.

To address questions concerning the "net energy" of each system, the results are expressed in several ways. As suggested by Bullard,[7] lifetime energy requirements per unit output are given for several energy forms. This can allow one to rank-order systems depending on the relative value of competing energy resources.

Because of differences in societal values of various energy forms, the concept of "potential electricity generation" is introduced. This transforms a set of energy requirements into the equivalent electrical energy that could have been generated with today's technology. Using this concept, the costs of electricity-generating systems can be weighed against their benefits in terms of a common energy form.

The energy-sink effect of rapid growth rates in building new electricity systems can be evaluated from knowledge of the system's construction time and energy payback period once the system is operational. The time required for each system to become energy profitable is calculated.

The time dependence of a system's energy costs and benefits can also be graphically displayed. Several examples are included.

An Appendix is included to describe the analysis in greater depth. Detailed tables of capital and operating requirements for each facility are included. With some minor aggregations and disaggregations, these are given by 2-digit or 4-digit Bureau of Economic Analysis (BEA) categories.

2. METHODOLOGY

This section outlines the computational procedures for obtaining the direct and indirect energy requirements for constructing and operating a single energy supply facility. Facility requirements are then appropriately combined to give total system requirements.

2.1 FACILITY ENERGY COSTS

During the construction period of a facility, large amounts of energy are indirectly consumed in the form of capital goods. Also, some direct energy is used to operate the construction equipment. However, this requirement is usually much less than the indirect energy use. Figure 1A gives an energy flow diagram for this period of time. Given the material requirements for constructing a facility, the energy embodied in these requirements is calculated according to Ref. 6. Table 2 gives the primary data sources for the construction requirements of each facility. In general, the requirements are distributed over a several year period.

Once a facility is operational, it produces an energy output. To produce this output a facility requires material and service inputs including its direct energy requirements. These facts are schematically represented in Fig. 1B. As for capital requirements, the total energy use during operation is obtained from input-output analysis. Table 2 also lists the data sources for the annual operating requirements of each facility.

For purposes of analysis the annual output of each facility is measured in Btu's. Capital and operating requirements per unit annual output for each facility are given in the Appendix.

Figure 1. Energy Inputs and Outputs for an Energy Facility

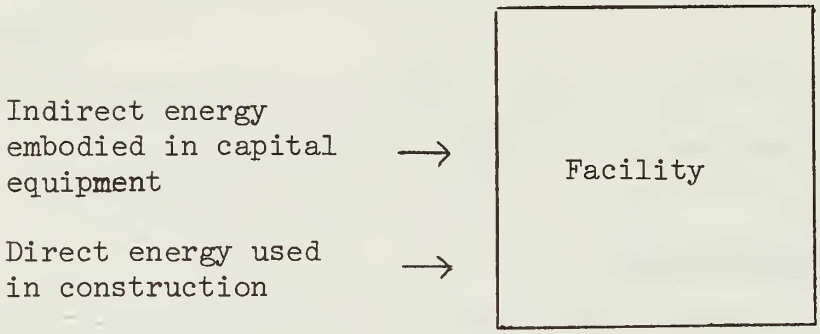


Figure 1A. Construction Period

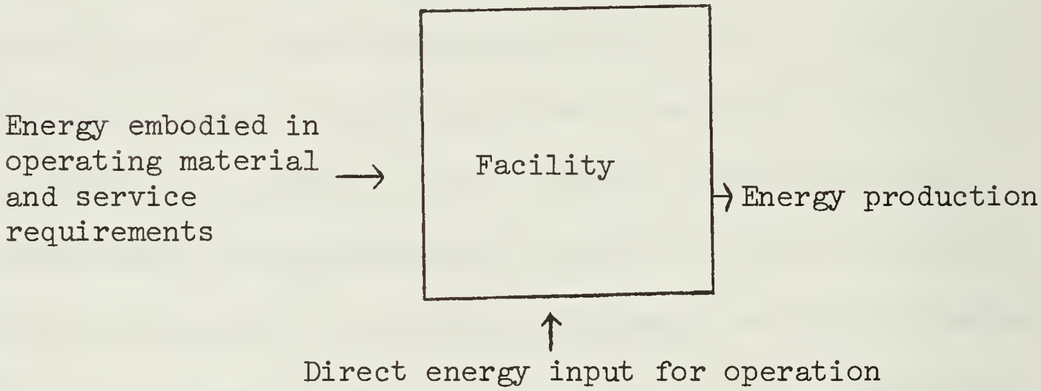


Figure 1B. Operation Period

Table 2

Data Sources for Facility Requirements

Facility	Construction	Operation
Coal Mine (Underground eastern mine)	B	CAC_{90}
Natural Gas Production (Offshore)	B	CAC_{90}
Crude Oil Production (Onshore)	B	CAC_{90}
Oil Shale Mine/Retort	M	M
LWR Fuel Mine/Processing	CM	CM
HTGR Fuel Mine/Processing	CM	CM
Solvent Coal Refinery	M	M
Coal Gasification (High Btu)	M	M
Oil Refinery (Low-gasoline)	B	CAC_{90}
Natural Gas Utility	BCL	CAC_{90}
Coal Combined Cycle Power Plant	M[a]	M[b]
Coal-Fired Power Plant	B	CAC_{101}
Oil Fired Power Plant	B	CAC_{101}
Gas-Fired Power Plant	B	CAC_{101}
LWR Power Plant	M	M[b]
HTGR Power Plant	M	M[b]

B - Bechtel (Ref. 8, adapted to 90-order requirements vector.)
M - MITRE (Ref. 9, adapted to 357-order requirements vector.)
CM - Nuclear fuel processing direct and indirect energy requirements are calculated according to Ref. 5. For more details see the Appendix.
BCL - Battelle (Ref. 10, adapted to 90-order requirements vector.
CAC_{90}, CAC_{101} - Center for Advanced Computation 90-order and 101-order input-output model data (Refs. 11 and 12).
a - a combination of a low Btu coal gasification plant and a COGAS gas turbine topping cycle power plant. To demonstrate data differences the results also include using Bechtel data for the gasification facility capital requirements.
b - Operating requirements for these power plants are increased to account for electricity transmission, distribution, and administration requirements[13]. Other power plant requirements already include these costs.

2.2 SYSTEM ENERGY COSTS

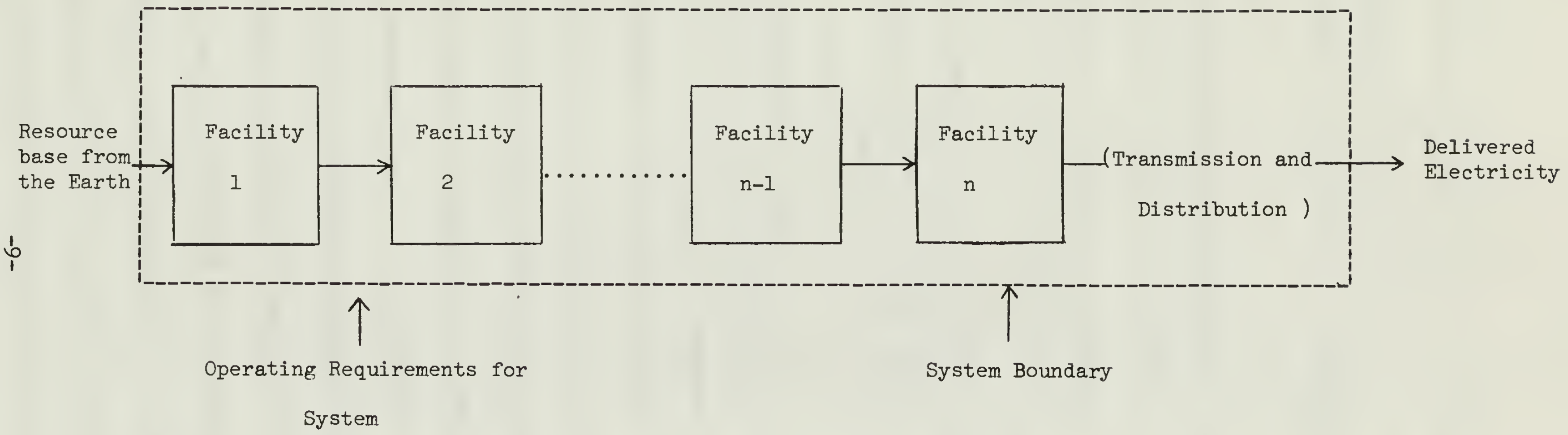
An electricity-generating system consists of several facilities to extract the energy resource from the earth, process it, and ultimately produce and distribute electricity. Table 1 listed the facilities considered in defining our nine electricity-generating systems.

Figure 2 is a schematic representation of a series of facilities defining a complete system. The initial facility in a system is typically a mine or well that extracts the direct-energy resource consumed by the system. The n^{th} facility is the electricity-generating facility such as a nuclear power plant. Intermediate facilities represent fuel processing, distribution, or conversion facilities.

The energy requirements to construct a system is essentially the sum of the requirements for the separate facilities. Facility sizes from Refs. 8-10 are in the range of economic capacities and typical of existing or future facilities. Facility capacities, load factors, and efficiencies are combined to determine the number (or fraction) of individual facilities required to complete the system. System requirements are then the sum of the appropriate amount of the capital requirements of the individual facilities.

The operating requirements for a system are not merely the sum of the facility operating requirements. Except for the initial facility in a system, the direct fuel requirements of a facility do not cross the system boundary. This is illustrated in Fig. 2. As shown in the Appendix, the system energy requirements per Btu of generated electricity is:

Figure 2. Schematic of Electricity-Generating System



$$\underset{\text{Fuel energy removed from the earth}}{\left(\sum_{i=1}^{n} \frac{1}{\eta_i}\right)\cdot \underline{e}} + \underbrace{\left[\sum_{i=1}^{n-1}\left(\prod_{j=i+1}^{n}\frac{1}{\eta_j}\right)\cdot \underline{\underline{\varepsilon}}*\underline{OP}_i\right]}_{\text{First n-1 facilities}} + \underbrace{\underline{\underline{\varepsilon}}*\underline{OP}_n}_{\text{Final Facility}}$$

η_i = fuel conversion efficiency of the i^{th} facility (Btu output from facility i per Btu input to facility i).

$\underline{\underline{\varepsilon}}$ = matrix of direct and indirect energy intensities (appropriate order-90,101, or 357).

$\underline{OP}_i$ = vector of operating requirements per unit (Btu) output from the i^{th} facility. (Direct fuel requirement of each facility is zeroed.)

$\underline{e}$ = vector of energy requirements from the earth (OP_i only includes economic transactions from one sector of the economy to another).

As shown in Fig. 2 the system boundary encompasses the transmission and distribution of electricity to the final user. Transmission line losses and other electricity requirements of the final facility in each system are assumed to be supplied by the system itself. Therefore, the delivered electricity will be somewhat less than that generated.

This methodological approach implicitly assumes that the technological system is separated from the economic system. Therefore, this analysis is only appropriate for a marginal technology (which is usually the case for the nine systems). For example, if an economic system were dominated by shale oil inputs for crude oil, the total energy requirements for a shale-electric system would be greater than that from the present U. S. economy whose crude requirements come primarily from oil wells.

3. RESULTS

The results presented here depend both on the accuracy of input-output techniques and the accuracy of data for the individual facility requirements. References 3 and 6 give excellent discussions on potential difficulties in applying input-output analysis to obtain indirect energy requirements. The reader is referred to the Appendix for a detailed description of the data used in the present analysis. As noted there, the data sources for facility requirements are not necessarily consistent. Because of vast differences (nearly a factor of six in capital intensiveness) in two data sources for the capital requirements of a low Btu coal gasification facility, results for the coal combined cycle are given for each data source.

The total energy required to build and operate the nine electricity-generating systems is presented in Table 3. Energy costs are separated into coal, crude (oil and gas), and total primary energy. In keeping with U. S. Bureau of Mines convention, primary energy includes the sum of the first two energy forms as well as the fossil fuel equivalent of non-fossil generated electricity. Energy costs in Table 3 are given for construction and for the total system lifetime (25 years of operation). Nuclear fuel is considered a primary energy source, equivalent to the primary fossil fuel that would have been required by fossil-electric systems to produce the nuclear generated electricity (for more details, see the Appendix).

Results for the coal combined cycle system are given for both the MITRE and Bechtel low Btu coal gasification facility capital requirements. Differences in capital intensiveness (see Appendix) for this facility result in the Bechtel system requiring more than twice the construction

Table 3. Comparisons of Energy Costs
For Nine Electricity-Generating Systems

SYSTEM	CAPITAL COST (Btu/Btu Annual Output)			LIFETIME COST (INCLUDING FUEL)[a] (Btu/Btu Total Output)			LIFETIME COSTS (OTHER THAN FUEL)[a] (Btu/Btu Total Output)		
	Coal	Crude	Primary	Coal	Crude	Primary	Coal	Crude	Primary
CM-CFPP	.18	.27	.47	3.12	.09	3.21	.04	.09	.13
CM-CG-NGU-GFPP	.35	.56	.95	5.06	.25	5.32	.06	.25	.32
CM-CCC	.14 (.33)[b]	.21 (.46)	.36 (.84)	2.54 (2.55)	.03 (.04)	2.58 (2.60	.02 (.02)	.03 (.04)	.05 (.07)
CM-SRC-CFPP	.27	.41	.71	5.29	.45	5.74	.05	.45	.50
GP-NGU-GFPP	.39	.67	1.09	.05	3.46	3.52	.05	.37	.44
CO-LGR-OFPP	.70	1.26	2.02	.09	3.70	3.81	.09	.62	.73
SO-LGR-OFPP	.30	.48	.81	.08	5.20	5.30	.08[c]	.58[c]	.68[c]
LWR	.31	.35	10.53 (.74)[c]	.09	.09	4.23	.09	.09	.21
HTGR	.50	.56	17.13 (1.17)[c]	.09	.08	4.45	.09	.08	.19

[a] A 25-year lifetime is assumed for all facilities. (This may be overly optimistic for oil wells. If so, their energy costs are underestimated.) Fuel costs are considered to be all energy entering the initial facility from the ground. Several facilities actually use some of this energy to satisfy part of their operating requirements.

[b] Results in parenthesis result when Bechtel construction requirements for the low Btu coal gasification facility are used instead of MITRE's.

[c] Non-fuel related primary energy requirements in parenthesis.

energy requirements of the MITRE system. However, the total lifetime energy costs are similar for the two cases.

Lifetime non-fuel costs for the oil-electric system (onshore oil well, refinery, and oil-fired power plant) are higher than any other system. This result illustrates a basic fact that underlies the need for net energy analysis: As nonrenewable resources become scarcer, it requires more and more energy to get them out of the ground. For example, Bechtel oil production capital costs assume 3 dry-holes for every 4 onshore wells drilled in the contiguous states.

Figure 3 graphically compares the energy costs and benefits over time for oil-electric and shale-oil-electric systems that deliver 20 trillion Btu's of electricity per year. Delivered electricity is plotted above the axis while total primary energy costs are plotted below. The very high capital costs for onshore oil is obvious when one realizes that wells are being drilled during only the last two of the five year construction period. Because of energy conversion inefficiencies total operating costs will always be greater than electricity benefits on a Btu basis. The substantially greater total operating requirements for shale oil are due to the energy intensive shale oil mining and retorting facility.

A similar graphical comparison of the light water reactor (LWR) and high temperature gas-cooled reactor (HTGR) systems is given in Figure 4. Here the fuel and non-fuel primary energy requirements are separated. Nuclear fuel is costed as a primary energy source equivalent to the primary fossil energy needed to generate a similar amount of electricity (see Appendix for details). Higher initial fuel enrichment

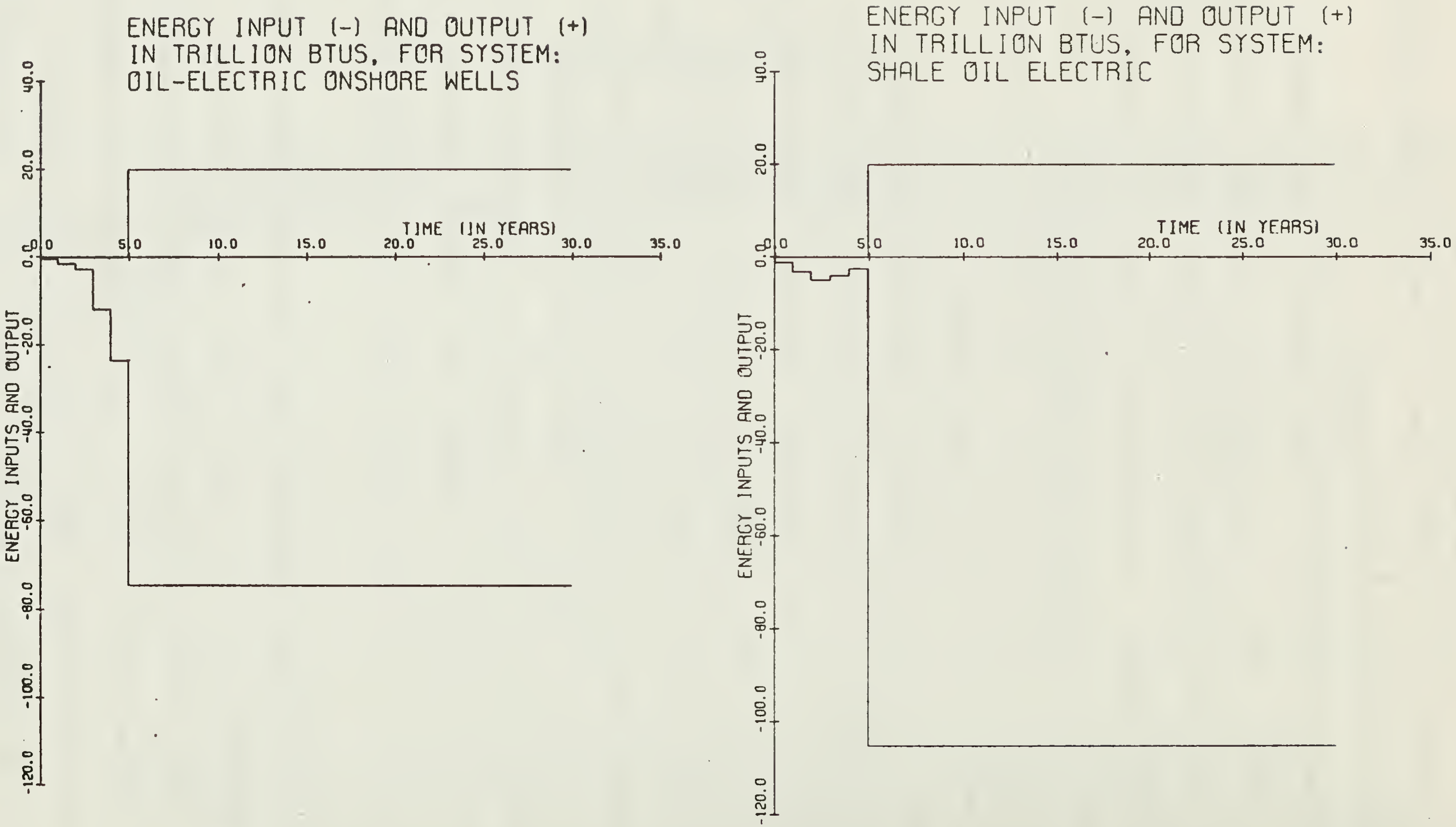


Figure 3. Energy Costs (total primary) and Benefits (delivered electricity) Over Time for Oil-Electric and Shale-Oil-Electric Systems.

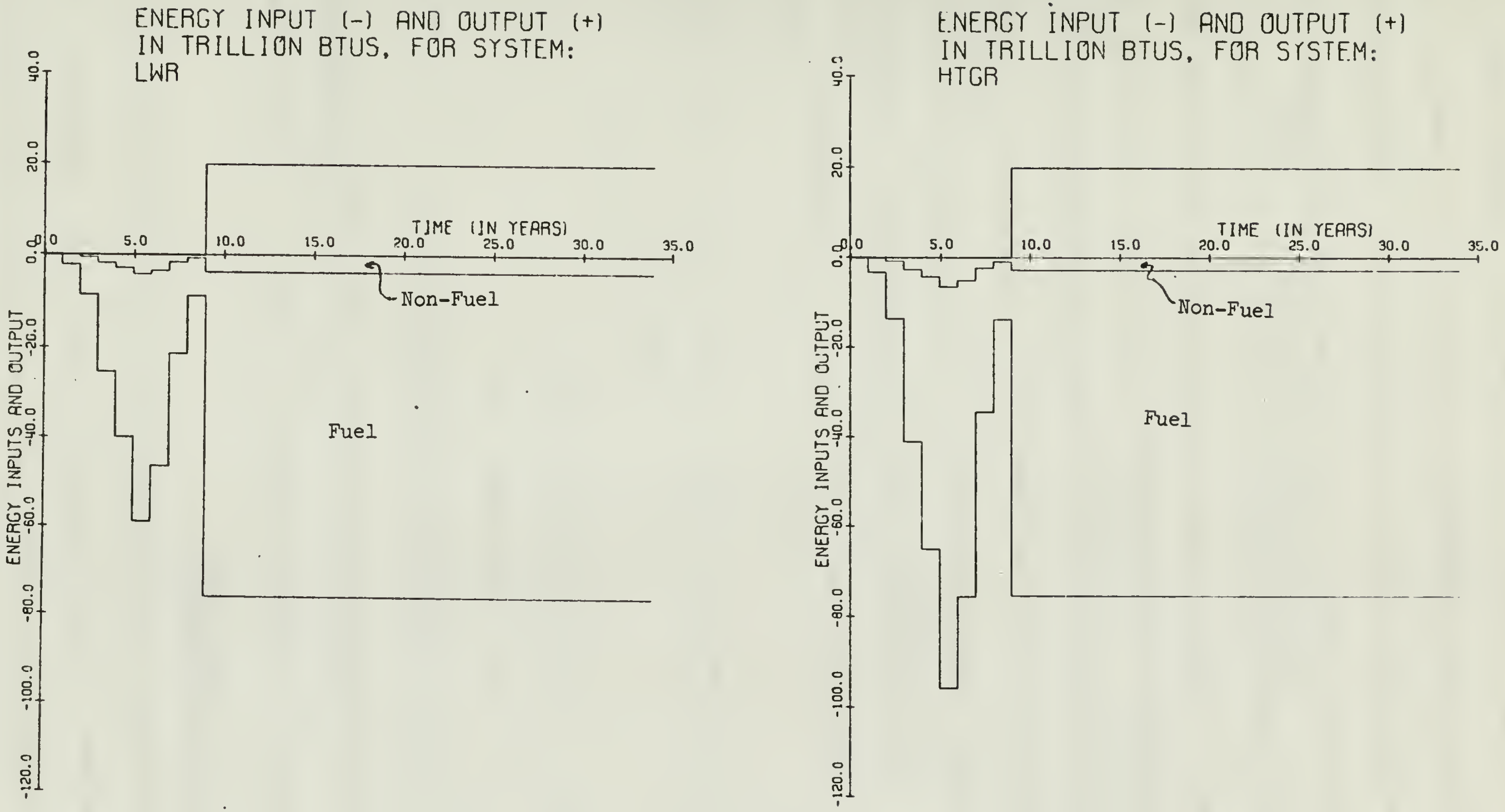


Figure 4. Energy Costs (fuel and non-fuel primary) and Benefits (delivered electricity) Over Time for LWR and HTGR Electric Systems.

requirements result in HTGR's being more capital energy intensive. However, non-fuel lifetime costs of LWR's are somewhat higher (see Table 3).

Even when fuel requirements are neglected, an energy supply system is a net energy sink until the capital and some operational energy costs are repaid by the system. Table 4 gives the energy payback times for the non-fuel capital and operating energy costs incurred up to the time of repayment. Payback times are given for two cases: 1) The time required to repay the total primary requirements (other than fuel) with electricity on a Btu basis and 2) the time required to repay the electricity that could have been generated and delivered by diverting the non-fuel energy requirements through existing electricity generation systems. This "potential electricity generation" is calculated from the following relationship, which is derived in the Appendix:

$$\text{Potential Electricity (Btu)} = .2687 * E_{\text{coal}} + .2473 * E_{\text{crude}} + .1888 * E_{\text{electricity}}$$

E_{coal} = Coal requirement (Btu)

E_{crude} = Crude requirement (Btu)

$E_{\text{electricity}}$ = Electricity requirement (Btu).

Because a Btu of electricity is valued more by society than a Btu of primary energy, the second comparison in Table 4 is probably more valid.

4. SUMMARY AND CONCLUSIONS

A methodology for evaluating total energy costs for energy supply systems has been developed employing input-output techniques. Using a number of data sources for various energy supply facilities, the direct and indirect energy costs for construction and operation of nine electricity-generating systems were evaluated. Future analyses of this nature should

Table 4. Energy Payback Times (Years)

System	Electricity for Primary	Electricity for Potential Electricity
CM-CFPP	.54	.13
CM-CG-NGU-GFPP	1.32	.26
CM-CCC	.37 (.87)[a]	.09 (.22)[a]
CM-SRC-CFPP	1.35	.21
GP-NGU-GFPP	1.81	.31
CO-LGR-OFPP	5.71	.62
SO-LGR-OFPP	2.31	.25
LWR	.90	.20
HTGR	1.37	.32

[a] Results using Bechtel data for low Btu coal gasification facility in parenthesis.

pay particular attention to obtaining consistent facility requirements data to reduce possible error. This can probably best be accomplished by using a single data source. Inclusion of all transportation-related capital and operating requirements should be considered before policy decisions based on net energy analyses are made (see Appendix).

Except for extremely rapid energy supply expansion rates (system doubling times on the order of 2 or 3 years), the electricity systems investigated would repay their non-fuel energy costs in a short period of time after commencement of normal operation. In less than two-thirds of a year of operation all systems are able to generate more electricity than could have been generated if the non-fuel energy requirements to build and operate them had been used to produce electricity from existing systems (see Table 4). However, inclusion of all transportation requirements could significantly delay this repayment period.*

As resource supplies (energy and non-energy) dwindle, energy payback times for these systems will inevitably increase. More energy will be required in the extraction of nonrenewable energy resources as well as other physical resources. The decreasing success rate of new oil wells in the contiguous states is the principal reason why the oil-electric system has the greatest repayment period. Chapman and Mortimer found analogous results when they considered nuclear-electric plants that were fueled with low-grade uranium ores.[5]

---

*For example, electric transmission operating requirements are included, but the capital requirements do not include the construction of energy-intensive aluminum transmission lines.

REFERENCES and NOTES

1. E. Hirst and R. Herendeen, "Total Energy Demand for Automobiles," Society of Automotive Engineers Paper 730065, New York, New York, January 1973.

2. E. Hirst, *Energy Use for Food in the United States*, Oak Ridge National Laboratory Report ORNL-NSF-EP-57, October 1973.

3. C. Bullard and R. Herendeen, "Energy Impact of Consumption Decisions," Proceedings of the IEEE, Vol. 63, No. 3, March 1975.

4. *The Energy Conservation Papers,* Ford Energy Policy Project, Chapters 3 and 4, Ballinger Publishing Co., Cambridge, Mass., 1975.

5. P. F. Chapman and N. D. Mortimer, *Energy Inputs and Outputs for Nuclear Power Stations*, Open University Report ERG 005, December, 1974.

6. C. Bullard and R. Herendeen, *Energy Costs of Goods and Services, 1963 and 1967,* Document No. 140, Center for Advanced Computation, University of Illinois, Urbana, 61801, November 1974.

7. C. Bullard, *Net Energy as a Policy Criterion*, Document No. 154, Center for Advanced Computation, March 1975.

8. Bechtel facility construction data supplied to CAC in conjunction with work related to evaluating Project Independence alternatives. Also see Bechtel Energy System Group, *Path to Self-Sufficiency Directions and Constraints*, August 1974, and Ref. 18.

9. J. Just, et al., *New Energy Technology Coefficients and Dynamic Energy Models* (2 volumes), MITRE report MTR-6810, January 1975.

10. C. Chilton and W. Fisher, *An Ex Ante Capital Matrix for the United States, 1970-1975*, Battelle Memorial Institute, Columbus Laboratories, March 1971

11. The 90-order model is essentially an aggregation of the 357 order model described in ref. 6 to 2-digit BEA classifications.

12. C. Bullard, *An Input-Output Model for Energy Demand Analysis*, Document No. 146, Center for Advanced Computation, January 1975.

13. R. Istvan, *Report to the Interagency Growth Project: 1980 Inputs for Private Electric Utilities*, Harvard Economic Research Project, August, 1972.

14. Edison Electric Institute, *Historical Statistics of the Electric Utility Industry Through 1970*, 1973.

15. *Input-Output Structure of the U. S. Economy, 1967*, Vols. 1-3, U. S. Department of Commerce, Bureau of Economic Analysis, 1974.

16. C. Bullard and D. Pilati, *Direct and Indirect Requirements for a Project Independence Scenario*, Center for Advanced Computation, in progress.

17. D. Simpson and D. Smith, *Direct Energy Use in U. S. Economy, 1967*, Technical Memorandum No. 39, Center for Advanced Computation, January 1975.

18. M. Carasso, et al, *The Energy Supply Planning Model*, Bechtel Corp. Energy Systems Group draft final report, Vols. 1-3, July 1975.

APPENDIX

A. Input-Output Analysis

Input-Output analysis provides the tool with which indirect energy requirements can be calculated. References 3 and 6 provide detailed descriptions of the method employed in this analysis. A brief description of the technique is included here.

The Bureau of Economic Analysis (BEA) provides detailed information on the dollar value of interindustry transactions (flows) of goods and services. The latest year for which these data are available is 1967.[15] Energy transaction data were obtained from Ref. 17.

Using BEA data, a matrix of technological coefficients, A_{ij}, is defined as the amount of industrial sector i's output sold to sector j per unit of j's output. The total output of industry i (X_i) consists of that sold to other industries and that sold to final demand (Y_i). Mathematically, this can be represented as

$$X_i = \sum_j A_{ij} X_j + Y_i$$

Or, in matrix notation,

$$\underline{X} = \underline{\underline{A}}\, \underline{X} + \underline{Y}$$

For a given final demand vector, the total requirements can be obtained through matrix inversion,

$$\underline{X} = (\underline{\underline{I}} - \underline{\underline{A}})^{-1}\, \underline{Y}$$

where $\underline{\underline{I}}$ is the identity matrix.

Analogously, total energy requirements for a bill of goods is obtained from the energy sector requirements when the $\underline{\underline{A}}$ matrix includes physical data on energy flows. Thsi matrix has been generated at the Center for Advanced Computation, University of Illinois, for several levels of BEA classifications. The data used in this report required the CAC 90-, 101-, and 357- order A matrices to calculate the indirect energy requirements.

B. Data Sources

This report is methodological in nature but relies on a number of data sources in applying the developed techniques. Inconsistencies and other differences in the basic data will result in some uncertainty in the final results. Most of the caveats underlying the results are presented in this section.

MITRE[9] capital and operating data are used for six of the facilities (see Table 2). These data are reported at the 367-order level of BEA disaggregation in 1967 producers costs. The requirements are aggregated to 357-order for indirect energy calculations. Construction costs include purchases from non-residential construction (BEA 11.02) and therefore comprise some of the on-site labor costs. Leased construction equipment is given as purchases from the business services sector. Because this equipment is only a small portion of that sector's output, the resulting energy content is incorrect (probably underestimated). Operating requirements of MITRE electric plants do not include transmission, distribution, and administrative costs. To maintain consistency with other power plants, these requirements are increased to account for these costs using data from Ref. 13. For nuclear systems, MITRE capital costs do not include initial core fuel costs. Also, operating fuel requirements are purchased from the industrial chemicals sector. Because of the capital omission and the atypical characteristics of nuclear fuel as a chemical, this report relied on fuel processing energy costs reported in Ref. 5 for both capital and operation (see next section).

Bechtel[8] provides the capital requirements for seven of the facilities. These are given for 20 categories in 1974 dollar costs to a contractor. Reference 16 describes the methodology employed to obtain these requirements in 1967 producer's costs for use with the 90-order input-output model. Bechtel allocated the appropriate fraction of the capital cost of leased equipment to the sector producing the equipment. Therefore, the difficulties encountered by MITRE for leased machinery is surmounted. Bechtel costs were generated in-house and all design and on-site labor costs appear in value added. Bechtel capital costs are given for each construction year. Their capital expenditure distributions over time are assumed for MITRE cases for similar facilities.

MITRE and Bechtel provide the bulk of the capital cost information. A comparison of the capital intensiveness (on a per Btu output basis) of similar facilities is given in Table A-1. This provides a first-order check on data differences. (A better comparison would include differences in sector distributions of the capital costs.) The greatest disparity occurs for the low Btu coal gasification facility (part of the coal combined cycle) where the Bechtel dollar costs (per Btu output) are nearly 6 times that of MITRE. There are several reasons which might explain these differences. First, MITRE considered a Texaco gasification facility which differs from the Lurgi process considered by Bechtel. Lurgi systems have been in use for a number of years. Their costs are well known and somewhat expensive. On the other hand, the Texaco system is not in full-scale

Table A-1. Data Comparison of Facility Capital Intensiveness

Data Source	Facility	Output Capacity	Capital Intensiveness[a] (Dollars/Btu Annual Output)
Bechtel	LWR[b]	1100 MWe	4.8×10^{-6}
MITRE	LWR	1000 MWe	5.4×10^{-6}
Bechtel	HTGR[b]	1500 MWe	5.9×10^{-6}
MITRE	HTGR	770 MWe	7.2×10^{-6}
Bechtel	Oil shale mine/retort[c]	88,000 BBL/D	1.4×10^{-6}
MITRE	Oil shale mine/retort	50,000 BBL/D	1.5×10^{-6}
Bechtel	High Btu coal gasification	2.4×10^{11} Btu/D	3.3×10^{-6}
MITRE	High Btu coal gasification	5.0×10^{11} Btu/D	1.2×10^{-6}
Bechtel	Low Btu coal gasification	2.8×10^{11} Btu/D	2.7×10^{-6}
MITRE	Low Btu coal gasification	1.4×10^{11} Btu/D	4.7×10^{-7}
Bechtel	Solvent refined coal	1.8×10^{11} Btu/D	1.7×10^{-6}
MITRE	Solvent refined coal	1.8×10^{11} Btu/D	8.7×10^{-7}

[a] Does not include value added. For comparable facilities MITRE costs should be somewhat greater due to the fact that their expenditures include some construction labor costs. These costs are part of value added in Bechtel data.

[b] Capital costs of nuclear plants do not include fuel costs for initial core.

[c] Combination of two Bechtel facilities.

operation and its cost estimates are probably optimistic. Therefore, results are presented for the coal combined cycle using both data sources for the low Btu coal gasification facility.

Operating requirements for eight of the facilities are provided by the CAC data base. These data are principally obtained from actual transactions for sectors that parallel the facilities. These data tend to be all-inclusive and therefore greater than engineering cost projections of operating costs such as MITRE's.

Except for the coal combined cycle, a natural gas utility is included as a facility requirement of systems that ultimately burn gas. A natural gas utility is a distribution network of pipelines providing one step in the overall delivery of energy. The coal combined cycle is envisioned as a mine-mouth operation and would therefore have zero transportation requirements. Natural gas utility capital requirements are obtained from Ref. 10 and the operating requirements are part of the CAC data base.

Because of a lack of data at the time of this analysis, energy transportation requirements are not properly treated. Only natural gas distribution and the operating requirements for electricity transmission are included in the analysis. Recent preliminary data imply that the inclusion of all transportation facilities might result in increasing the construction energy costs by a factor of two or more. Bechtel has evaluated the total capital costs of energy supply and transportation facilities for a particular Project Independence scenario.[18] The 10-year cumulative results for the entire U. S. energy system imply that 44% of the total capital costs will be incurred by transportation facilities. Also, 83% of the transportation capital costs are for electricity transmission and distribution. However, this inclusion would probably have little effect on the relative energy costs of various systems considered in this report, but would affect the payback periods. On the other hand, systems that rely heavily on other transportation facilities (e.g., most coal based systems) might not seem as favorable if capital costs of all all transportation facilities were included.

C. Nuclear Fuel Energy Costs

Besides the nuclear-electric plant, a complete nuclear-electricity system consists of an uranium mine, mill, conversion facility, enrichment plant, fuel rod fabrication facility and fuel reprocessing plant. Capital and operating data for this host of facilities were unavailable. However, Chapman and Mortimer[5] used a truncated process analysis method to estimate the total energy requirements for the nuclear fuel cycle with no fuel reprocessing capabilities. Given the amount of fuel required and its isotopic concentration of uranium-235, an estimate of the total (capital and operating) energy requirements to produce the fuel can be made.

Tables A-2 through A-5 give the step-by-step results for the nuclear fuel-cycle calculations. The core and annual fuel requirements for a boiling water reactor (BWR) and a pressurized water reactor (PWR) were obtained from the major manufacturers of these plants (Table A-2). An LWR is assumed 60% PWR's and 40% BWR's, based on projections of the mix of plants. The fuel requirements for a high temperature gas-cooled reactor (HTGR) were obtained from its manufacturer (Table A-2). The energy required to mine, mill and fabricate the thorium fuel requirements of the HTGR are assumed the same (per ton) as uranium. Reference 5

Table A-2

FUEL REQUIREMENTS FOR 1000 MWe NUCLEAR PLANTS

	Metric Tons of Fuel	
Reactor Type	Initial Core	Annual Refueling
LWR[a]	94.3(2.3)[b]	27.7(2.9)
HTGR	1.6(93.0) 32.3 Thorium	.36(93.0) 7.26 Thorium

---

[a] 60% of system assumed to be PWR and 40% assumed to be BWR. All values assume 80% load factor.

[b] Percent fuel enrichment.

Table A-3

NATURAL URANIUM AND SEPARATIVE WORK UNIT (SWU) REQUIREMENTS

Fuel Enrichment	Tonnes natural U per tonne fuel	Tonnes SWU per tonne fuel
2.3	4.46	2.42
2.9	5.76	3.6
93.0	201.63	220.[a]

---

[a] Source: Private communication with E. Von Holle, Oak Ridge Gaseous Diffusion Plant. Other values from Reference 5 for a .25% tails assay.

Table A-4.

ENERGY COSTS OF FUEL PROCESSES

Process	Energy Requirements (10^9 Btu)
Mining and Milling	.0776 (t) (per tonne U)
Conversion	.0046(e) + .0158(t) (per tonne U)
Enrichment	.709(e) + .0281(t) (per tonne SWU)
Fuel rod fabrication	.0141(e) + .0093(t) (per tonne fuel)

Source: Ref. 5. The (t) or (e) signifies whether the energy requirement is thermal or electric.

Table A-5.

ENERGY INTENSITIES FOR NUCLEAR FUEL[a]

Reactor Type	CAPITAL (Btu/Btu)[b]			OPERATING (Btu/Btu)[b]		
	Elec.	Refined Petroleum	Natural Gas	Elec.	Refined Petroleum	Natural Gas
LWR	.0831	.0184	.0046	.0354	.0070	.0017
HTGR	.1225	.0167	.0042	.0276	.0038	.0009

---

[a] Energy intensities based on annual output of electricity at a 80% load factor.

[b] The termal energy requirements calculated from Table A-4 are assumed 80% refined petroleum and 20% natural gas.

separates the total fuel cycle energy requirements into electrical and thermal. Thermal requirements are assumed 80% refined petroleum and 20% natural gas. In calculating total system requirements, the energy requirements for producing the fuel input were added to the nuclear power plant's refined petroleum, electricity, and natural gas requirements. These increases result in an increase in the coal and crude requirements as shown below.

$$\text{Additional coal requirements} = \varepsilon_{coal-rp} {*}E_{rp} + \varepsilon_{coal-el} {*}E_{el} + \varepsilon_{coal-ng} {*}E_{ng}$$

$\varepsilon_{coal-rp}$ = Btu's of coal required directly and indirectly to produce a Btu of refined petroleum.

$\varepsilon_{coal-el}$ = Btu's of coal required directly and indirectly to produce a Btu of electricity.

$\varepsilon_{coal-ng}$ = Btu's of coal required directly and indirectly to produce a Btu of natural gas.

E_{rp}, E_{el} and E_{ng} = Nuclear fuel cycle refined petroleum, electricity and natural gas requirements.

An analogous relation is used for the additional crude requirements.

Extraction from the ground of nuclear fuel is costed as a primary energy requirement based on the fossil-fuel equivalent for producing electricity. On the average, it required (in 1967) 3.265 Btu's of primary fossil energy to generate a single Btu of electricity. Therefore, the annual primary energy requirement to produce nuclear electricity is increased by 3.265 times the annual generation to account for the earth-supplied nuclear fuel. Unlike fossil plants, nuclear power plants have a large capital fuel requirement. The initial fuel core is equivalent to several years of operational fuel requirements. The following assumption

$$\text{Time equivalent of initial core} = \frac{\text{tons of initial fuel*initial enrichment}}{\text{annual tons of fuel*annual enrichment}}$$

results in LWR initial cores having the equivalent of about 2.7 years of fuel and an HTGR having about 4.4 years. These capital energy cost considerations are reflected in Table 3 and Fig. 4.

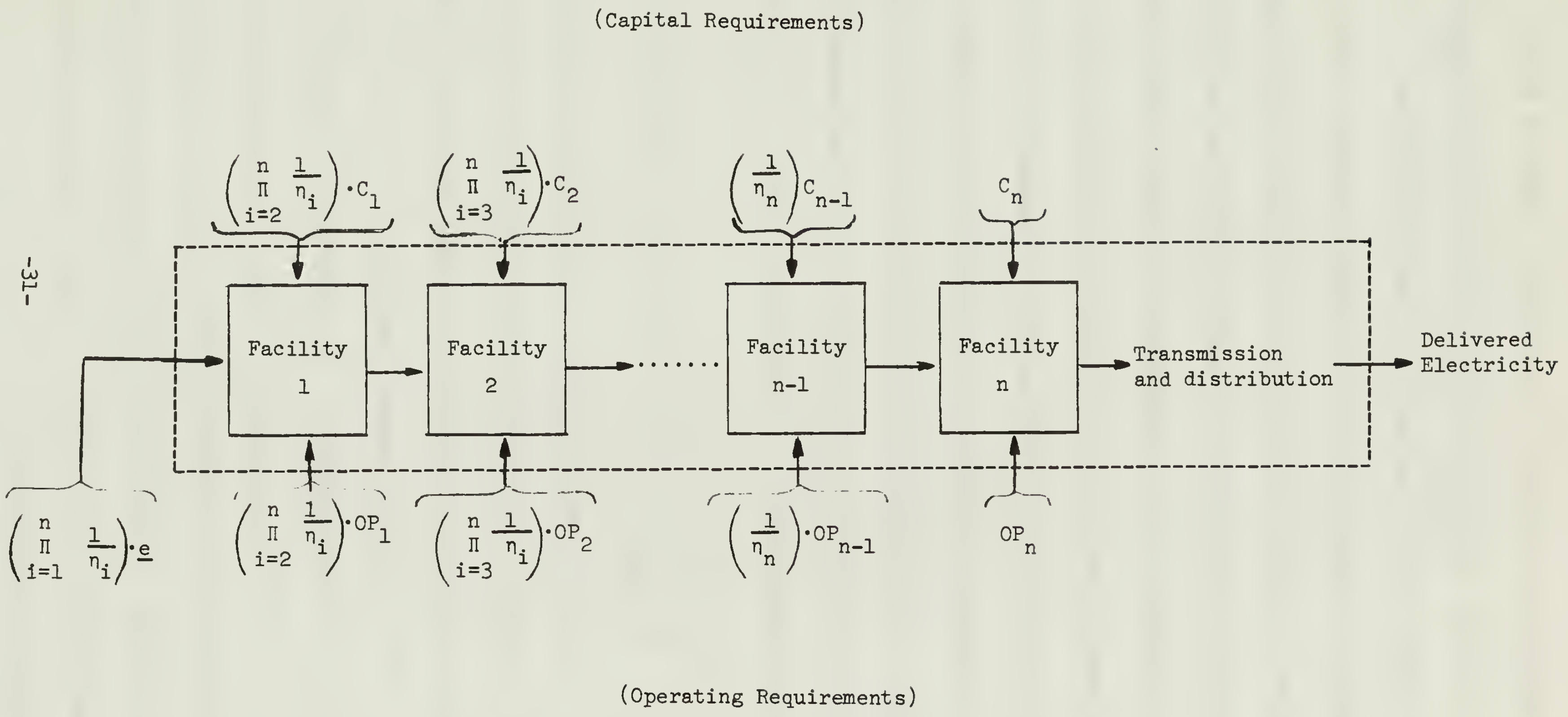
D. System Requirements

System energy requirements are obtained as a 6x(NC+1) matrix representing the annual energy requirements (coal, crude, refined petroleum, electricity, natural gas, and total primary) during each of the NC construction years and one year of operation. This section describes how this matrix is calculated from the facility data.

Figure A-1 is a schematic representation of the requirements for a generalized system. In that figure C_i represents a vector of capital requirements per unit output of facility i, OP_i represents a vector operating requirements per unit output of i, η_i is the energy conversion efficiency of the i^{th} facility, and $\underline{e}$ is a vector of input fuel energy from the earth to the initial facility. For fossil-fueled facilities $\underline{e}$ is a (6 x 1) vector whose primary energy and coal or crude elements are unity and zero elsewhere. For nuclear fuel only the primary term is non-zero (see last section).

As described in the beginning of the Appendix, the energy needed to produce a bill of goods is obtained from input-output analysis. The

Figure A-1. Schematic of System Capital and Operating Requirements



energy submatrix of $(I-A)^{-1}$ is ε $(6xN)$, where N is the appropriate number of sector (90, 101 or 357) for which the requirements are given. Therefore, $\underline{\underline{\varepsilon}}*\underline{C}_i$ gives the capital requirements per unit output for the i^{th} facility and $\underline{\underline{\varepsilon}}*\underline{OP}_i$ gives the energy needed to produce the operating requirements crossing the system boundary per unit output of facility i.

The total construction time of a system is assumed the maximum construction time of the component facilities. The capital requirements for each facility are distributed over time[8] and are expressed as a matrix $\underline{\underline{C}}$ (N x number of years to construct). Construction of each facility is phased so that each come on line simultaneously. This results in $\underline{\underline{C}}$ becoming an (N x NC) matrix with zero requirements in those years that the particular facility is not under construction. The capital energy requirements per unit of system output for any year t are

$$\sum_{i=1}^{n-1}\left(\prod_{j=i+1}^{n}\frac{1}{\eta_j}\right)*\underline{\underline{\varepsilon}}*\underline{C}_i(N,t) + \underline{\underline{\varepsilon}}*\underline{C}_n(N,t).$$

Thus, the fact that one Btu output from a system requires more than one Btu output from all facilities except the final one is included. Multiplication for each construction year gives the first NC columns of the 6 x (NC + 1) requirements matrix.

The operating requirements are assumed the same for each year of operation. Note that $\underline{\underline{\varepsilon}}$ multiplication only accounts for the energy transmitted through transactions from sectors of the economic system. Therefore, energy transmitted to the system directly from the earth has to be accounted for separately. Annual operating requirements per unit output for the system become

$$\prod_{i=1}^{n}\left(\frac{1}{\eta_i}\right)\underline{e} + \sum_{i=1}^{n-1}\left(\prod_{j=i+1}^{n}\frac{1}{\eta_j}\right)\underline{\underline{\varepsilon}}_i*\underline{OP}_i + \underline{\underline{\varepsilon}}_n*\underline{OP}_n$$

Note that $\underline{OP}_i$ is the operating requirements vector for a facility with the direct energy input zeroed. This is due to the fact that an operating requirement supplied directly to a facility from another facility in the system does not cross the system's boundary. Figure A-2 illustrates this fact for a coal-electric system consisting of a coal mine and a coal-electric plant. The coal plant requires OP_2 plus its coal input for operation. However, the coal input to the plant does not cross the system boundary and would be double-counted if included in the system's requirements.

Figure A-2. System and Facility Boundaries

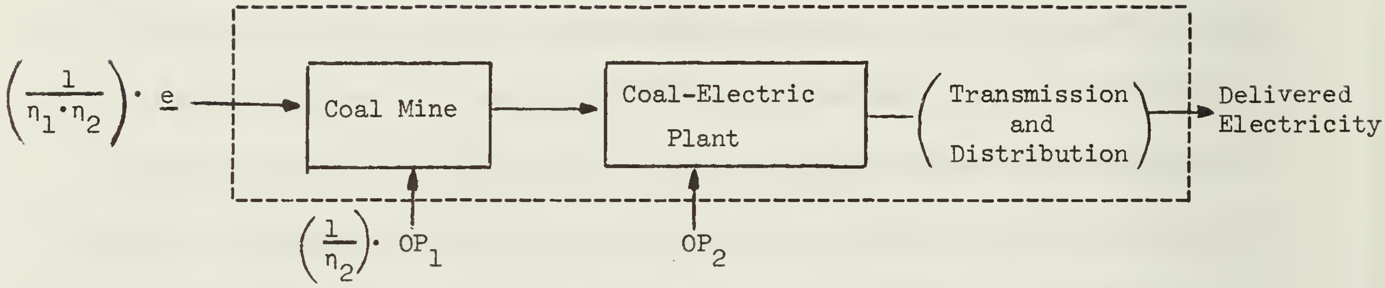


Figure A-2.A System Boundary

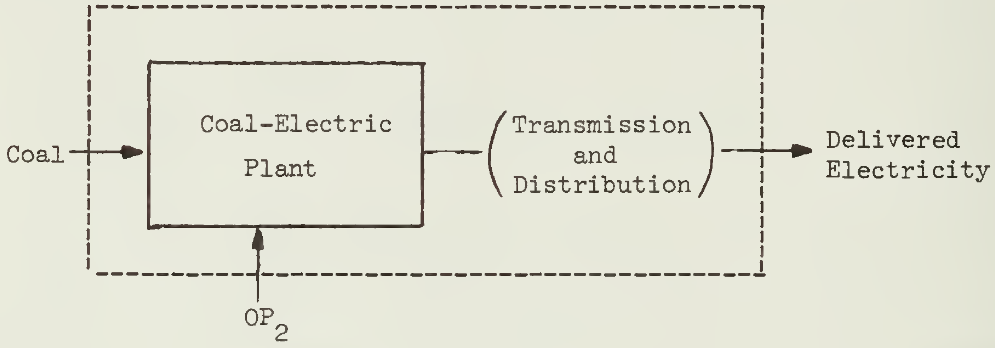


Figure A-2.B Facility Boundary

E. Potential Electricity

The concept of potential electricity is introduced to compare system energy costs on a common ground. Given a set of energy requirements E_{coal}, E_{crude} and $E_{electricity}$, potential electricity is calculated from the following:

$$\begin{aligned}
\text{Potential electricity} &= (\text{Electricity from non-fossil sources}) + \\
&\quad (\text{Electricity from the coal requirement}) + (\text{Electricity from} \\
&\quad \text{the crude requirements}) \\
&= (\text{Fraction of non-fossil electricity})*E_{electricity} + \\
&\quad E_{coal} * \frac{(\text{Fraction of coal produced electricity})}{(\text{coal required for coal electricity})} + \\
&\quad E_{crude} * \frac{(\text{Fraction of crude produced electricity})}{(\text{Crude required for crude electricity})} \\
&= (\text{Fraction of non-fossil electricity})*E_{electricity} + \\
&\quad E_{coal} * \frac{(\text{Fraction of coal produced electricity})}{\varepsilon_{coal\text{-}electricity}} + \\
&\quad E_{crude} * \frac{(\text{Fraction of crude produced electricity})}{\varepsilon_{crude\text{-}electricity}} .
\end{aligned}$$

This formulation assumes that all coal required for electricity generation goes to coal-electric systems and that all crude required for electricity generation goes to crude-electric systems. This is not absolutely correct: For example, diesel-fueled trains and trucks are used to transport coal to coal-fired power plants. Therefore, the relationship is only an approximation. For 1967 technologies[6] and mix of electricity sources[14], the above becomes

$$\text{Potential electricity} = .2687*E_{coal} + .2473*E_{crude} + .1888*E_{electricity}$$

where all units are in Btu's.

F. Energy Payback Time

The payback time for capital and operating energy costs is obtained from the following equality

$$\text{Total Non-Fuel Capital Energy Cost} + \text{Annual Non-Fuel Operating Energy Cost}*\text{Payback Time} = \text{Annual Output}*\text{Payback Time}$$

or,

$$\text{Payback Time} = \frac{\text{Non-Fuel Capital Energy Cost}}{\text{Annual Output} - \text{Annual Non-Fuel Operating Energy Cost}}$$

The payback time for different basis (total primary or potential electricity) can be calculated using the appropriate cost information.

G. Facility Capital and Operating Requirements

The following pages contain tables giving the capital and operating requirements for 14 facilities (same order as Table 2 with nuclear fuel processing facilities deleted). These requirements are grouped by BEA sectors except for energy product requirements (e.g., space-heat) that appear as separate sectors for facilities using CAC 101-order operating requirements. Direct fuel requirements are not zeroed as they must be for system analysis. The coal combined cycle and nuclear systems do not include Istvan[13] overhead requirements. Nuclear facilities do not include energy costs for their fuel processing. However, all these factors were accounted for in the calculations performed.

TABLE A-6

NON-ZERO CAPITAL AND OPERATING COEFFICIENTS FOR A U.EAST.COAL MINE

DATA SOURCE: B & CAC VECTOR ORDER: (CAP) 90 & (OP) 90
ENERGY SECTORS IN BTUS/BTU; OTHERS IN $/BTU

SECTOR I/O CODE	CAPITAL COEFF	OPERATING COEFF
700	0.0	0.786803E-03
3101	0.0	0.117412E-02
6801	0.548601E-05	0.133500E-03
6802	0.737818E-05	0.113018E-03
200	0.495474E-10	0.0
400	0.392696E-10	0.0
500	0.0	0.202784E-10
900	0.122651E-09	0.216303E-09
1200	0.143180E-10	0.157496E-08
1600	0.132282E-10	0.871973E-09
1700	0.512691E-10	0.148709E-09
1800	0.142009E-11	0.0
1900	0.765163E-12	0.202784E-09
2000	0.632562E-09	0.148033E-08
2200	0.467244E-11	0.0
2300	0.260830E-09	0.0
2400	0.183695E-09	0.135190E-10
2500	0.0	0.135190E-10
2600	0.184563E-11	0.675948E-11
2700	0.273660E-09	0.340002E-08
3000	0.664778E-09	0.0
3102	0.912190E-10	0.0
3103	0.186215E-09	0.0
3200	0.124598E-08	0.182506E-08
3500	0.211210E-09	0.0
3600	0.278960E-08	0.770581E-09
3700	0.839093E-08	0.285250E-08
3800	0.496183E-08	0.540758E-09
4000	0.308064E-07	0.675948E-10
4100	0.312971E-10	0.284574E-08
4200	0.171612E-08	0.871973E-09
4300	0.0	0.932808E-09
4500	0.889540E-07	0.685411E-08
4600	0.268562E-07	0.0
4700	0.142515E-09	0.675948E-10
4900	0.373814E-08	0.304176E-09
5000	0.251276E-10	0.554277E-09
5200	0.495616E-09	0.0
5300	0.157874E-07	0.0
5400	0.967217E-10	0.0
5500	0.895364E-09	0.561037E-09
5600	0.410334E-10	0.0
5800	0.296620E-10	0.473164E-10
5900	0.171432E-12	0.0
6100	0.0	0.202784E-10
6400	0.846730E-10	0.202784E-10
6501	0.104734E-07	0.106800E-08
6503	0.455584E-08	0.574556E-09
6504	0.922826E-10	0.175747E-09
6505	0.130142E-09	0.135190E-10
6506	0.0	0.202784E-10
6600	0.214098E-09	0.344733E-09
6803	0.925551E-11	0.155468E-09
6900	0.266616E-07	0.458292E-08
7000	0.310280E-09	0.216979E-08
7100	0.361454E-09	0.107949E-07
7300	0.282628E-08	0.548193E-08
7500	0.212168E-09	0.419088E-09
7700	0.485000E-10	0.141949E-09
7800	0.183866E-10	0.141949E-09
7900	0.152331E-10	0.0
8100	0.337940E-09	0.567796E-09
8200	0.182375E-10	0.878733E-10

TABLE A-7

NON-ZERO CAPITAL AND OPERATING COEFFICIENTS FOR A OFFSHORE GAS PRO

DATA SOURCE: B & CAC VECTOR ORDER: (CAP) 90 & (OP) 90
ENERGY SECTORS IN BTUS/BTU; OTHERS IN $/BTU

SECTOR I/O CODE	CAPITAL COEFF	OPERATING COEFF
700	0.0	0.405741E-04
800	0.0	0.237080E-01
3101	0.186451E-01	0.592305E-03
6801	0.172204E-03	0.799224E-03
6802	0.231598E-03	0.189223E-01
200	0.155527E-08	0.0
400	0.123266E-08	0.0
900	0.384995E-08	0.0
1200	0.449436E-09	0.118860E-07
1600	0.415229E-09	0.0
1700	0.160932E-08	0.119809E-09
1800	0.445760E-10	0.0
1900	0.240182E-10	0.0
2000	0.407536E-09	0.0
2200	0.146666E-09	0.0
2300	0.818734E-08	0.0
2400	0.576611E-08	0.224642E-10
2500	0.0	0.499204E-11
2600	0.579335E-10	0.149761E-10
2700	0.447824E-08	0.408848E-08
3000	0.108786E-07	0.222146E-09
3102	0.286332E-08	0.0
3103	0.584522E-08	0.0
3200	0.203896E-07	0.851143E-09
3500	0.662982E-08	0.0
3600	0.359447E-07	0.207170E-08
3700	0.206798E-06	0.298524E-08
3800	0.224824E-08	0.0
4000	0.149189E-06	0.120807E-08
4100	0.982402E-09	0.0
4200	0.773940E-08	0.156001E-08
4300	0.448162E-07	0.121307E-08
4500	0.588070E-06	0.143022E-08
4700	0.0	0.119809E-09
4900	0.143070E-07	0.213909E-08
5000	0.788744E-09	0.199682E-08
5200	0.478960E-09	0.0
5300	0.161240E-07	0.403357E-08
5400	0.303606E-08	0.0
5500	0.281051E-07	0.624005E-10
5600	0.128802E-08	0.124801E-09
5700	0.0	0.399363E-10
5800	0.931078E-09	0.249602E-11
5900	0.538118E-11	0.0
6200	0.461200E-08	0.232130E-09
6400	0.265784E-08	0.748806E-11
6501	0.738700E-07	0.579076E-09
6503	0.391852E-07	0.451780E-09
6504	0.166971E-08	0.998408E-10
6505	0.398072E-09	0.424323E-10
6506	0.310751E-11	0.773766E-10
6600	0.672044E-08	0.309506E-09
6803	0.290526E-09	0.312002E-09
6900	0.190040E-06	0.327977E-08
7000	0.973955E-08	0.207669E-08
7100	0.113459E-07	0.606308E-07
7300	0.887160E-07	0.603537E-08
7500	0.665984E-08	0.426819E-09
7700	0.152240E-08	0.142273E-09
7800	0.577147E-09	0.157249E-09
7900	0.478162E-09	0.0
8100	0.106078E-07	0.216155E-08
8200	0.572465E-09	0.154753E-09

TABLE A-8

NON-ZERO CAPITAL AND OPERATING COEFFICIENTS FOR A ONSHORE OIL PROD

DATA SOURCE: B & CAC VECTOR ORDER: (CAP) 90 & (OP) 90
ENERGY SECTORS IN BTUS/BTU; OTHERS IN $/BTU

SECTOR I/O CODE	CAPITAL COEFF	OPERATING COEFF
700	0.0	0.405741E-04
800	0.0	0.958000E-03
3101	0.105529E 00	0.592305E-03
6801	0.279846E-03	0.799224E-03
6802	0.376370E-03	0.189223E-01
200	0.252747E-08	0.0
400	0.200320E-08	0.0
900	0.625656E-08	0.0
1200	0.730380E-09	0.118860E-07
1600	0.674789E-09	0.0
1700	0.261530E-08	0.119809E-09
1800	0.724406E-10	0.0
1900	0.390320E-10	0.0
2000	0.144987E-07	0.0
2200	0.238347E-09	0.0
2300	0.133052E-07	0.0
2400	0.937052E-08	0.224642E-10
2500	0.0	0.499204E-11
2600	0.941479E-10	0.149761E-10
2700	0.232061E-07	0.408848E-08
3000	0.563773E-07	0.222146E-09
3102	0.465320E-08	0.0
3103	0.949906E-08	0.0
3200	0.105667E-06	0.851143E-09
3500	0.107741E-07	0.0
3600	0.123142E-06	0.207170E-08
3700	0.711724E-06	0.298524E-08
3800	0.999809E-08	0.0
4000	0.112424E-06	0.120807E-08
4100	0.159650E-08	0.0
4200	0.125870E-06	0.156001E-08
4300	0.0	0.121307E-08
4500	0.120906E-05	0.143022E-08
4700	0.914631E-08	0.119809E-09
4900	0.113110E-06	0.213909E-08
5000	0.128179E-08	0.199682E-08
5300	0.320168E-07	0.403357E-08
5400	0.493390E-08	0.0
5500	0.456737E-07	0.624005E-10
5600	0.209317E-08	0.124801E-09
5700	0.0	0.399363E-10
5800	0.151310E-08	0.249602E-11
5900	0.874497E-11	0.0
6200	0.252430E-07	0.232130E-09
6400	0.431927E-08	0.748806E-11
6501	0.160200E-06	0.579076E-09
6503	0.936863E-07	0.451780E-09
6504	0.550665E-08	0.998408E-10
6505	0.459707E-09	0.424323E-10
6506	0.175883E-10	0.773766E-10
6600	0.109214E-07	0.309506E-09
6803	0.472136E-09	0.312002E-09
6900	0.475162E-06	0.327977E-08
7000	0.158277E-07	0.207669E-08
7100	0.184383E-07	0.606308E-07
7300	0.144173E-06	0.603537E-08
7500	0.108229E-07	0.426819E-09
7700	0.247405E-08	0.142273E-09
7800	0.937924E-09	0.157249E-09
7900	0.777061E-09	0.0
8100	0.172387E-07	0.216155E-08
8200	0.930316E-09	0.154753E-09

TABLE A-9

NON-ZERO CAPITAL AND OPERATING COEFFICIENTS FOR A SHALEOIL

DATA SOURCE: MITRE VECTOR ORDER: (CAP) 357 & (OP) 357
ENERGY SECTORS IN BTUS/BTU; OTHERS IN $/BTU

SECTOR I/O CODE	CAPITAL COEFF	OPERATING COEFF
3101	0.0	0.725000E-02
6802	0.0	0.640500E-02
900	0.165320E-08	0.0
1102	0.389247E-06	0.0
1103	0.771374E-07	0.0
1105	0.191633E-07	0.0
1202	0.0	0.120583E-07
1701	0.922732E-11	0.0
2009	0.510135E-12	0.0
2201	0.280500E-11	0.0
2202	0.367417E-11	0.0
2203	0.155883E-11	0.0
2204	0.263445E-11	0.0
2301	0.183110E-10	0.0
2302	0.665794E-10	0.0
2303	0.202289E-10	0.0
2304	0.490134E-10	0.0
2305	0.595527E-10	0.0
2306	0.292767E-11	0.0
2307	0.276805E-10	0.0
2605	0.0	0.229863E-09
2701	0.500875E-07	0.259742E-07
2704	0.0	0.193851E-07
3201	0.0	0.307738E-08
3202	0.436824E-09	0.0
3203	0.167495E-08	0.0
3403	0.154836E-11	0.0
3612	0.198907E-07	0.0
3617	0.127583E-07	0.0
4006	0.236916E-06	0.130457E-08
4007	0.142064E-08	0.0
4009	0.713487E-10	0.0
4101	0.0	0.165210E-08
4202	0.136312E-09	0.0
4206	0.478321E-09	0.0
4208	0.148299E-06	0.882168E-09
4301	0.509218E-07	0.133150E-08
4302	0.881846E-09	0.0
4501	0.543481E-08	0.0
4502	0.519663E-07	0.115466E-08
4503	0.0	0.930783E-08
4602	0.408225E-07	0.127704E-08
4603	0.715022E-09	0.0
4604	0.294841E-08	0.0
4701	0.150336E-09	0.0
4702	0.466991E-10	0.0
4703	0.612058E-10	0.0
4704	0.703284E-10	0.0
4801	0.799985E-10	0.0
4802	0.657671E-10	0.0
4803	0.277553E-10	0.0
4804	0.607421E-10	0.0
4805	0.682594E-10	0.0
4806	0.145671E-09	0.0
4901	0.652963E-07	0.108909E-08
4903	0.221986E-07	0.933504E-09
4906	0.125591E-07	0.777927E-09
4907	0.263429E-08	0.933514E-09
5101	0.224046E-08	0.0
5102	0.185619E-09	0.0
5103	0.698183E-10	0.0
5104	0.179094E-09	0.0
5201	0.469151E-09	0.0
5202	0.319551E-09	0.0
5203	0.206366E-08	0.0
5204	0.284590E-09	0.0
5205	0.815542E-09	0.0
5301	0.815854E-08	0.141495E-08
5302	0.208107E-07	0.0
5303	0.257469E-07	0.884340E-09
5304	0.328061E-08	0.106121E-08
5305	0.607968E-08	0.0
5306	0.233027E-09	0.0
5308	0.856588E-08	0.0
5502	0.176241E-09	0.0
5503	0.166953E-07	0.0
5603	0.167833E-08	0.122763E-08
5801	0.156607E-09	0.0
5803	0.273153E-09	0.0
5901	0.453474E-09	0.0
5902	0.632728E-09	0.0
5903	0.989216E-08	0.924921E-09
6001	0.866710E-08	0.0
6002	0.208038E-09	0.0
6101	0.259616E-10	0.0
6102	0.317301E-11	0.0
6103	0.142419E-10	0.0
6104	0.837191E-10	0.0
6105	0.168150E-11	0.0
6106	0.574464E-10	0.0
6107	0.859451E-11	0.0
6201	0.171177E-08	0.0
6202	0.160529E-07	0.926147E-09
6204	0.725447E-09	0.0
6205	0.957977E-10	0.0
6206	0.187441E-09	0.0
6207	0.139726E-11	0.0
6301	0.218999E-10	0.0
6303	0.670327E-10	0.0
6402	0.104390E-08	0.0
6404	0.623671E-09	0.0
6411	0.181750E-08	0.0
6412	0.521961E-09	0.0
6501	0.724873E-08	0.662938E-09
6502	0.0	0.378821E-09
6503	0.101050E-07	0.662938E-09
6504	0.367045E-09	0.0
6505	0.896126E-09	0.189349E-10
6506	0.0	0.170471E-09
6507	0.948164E-11	0.0
6600	0.0	0.177888E-08
6803	0.0	0.280915E-08
6901	0.384644E-07	0.481437E-08
6902	0.302606E-07	0.849596E-09
7004	0.0	0.388526E-07
7102	0.0	0.336545E-07
7202	0.0	0.223441E-09
7301	0.0	0.693095E-08
7303	0.0	0.468262E-08
7500	0.0	0.394795E-08
7701	0.0	0.170324E-08
8100	0.0	0.256260E-08
8200	0.0	0.258289E-09

TABLE A-10

NON-ZERO CAPITAL AND OPERATING COEFFICIENTS FOR A SR COAL

DATA SOURCE: MITRE   VECTOR ORDER: (CAP) 357 & (OP) 357
ENERGY SECTORS IN BTUS/BTU; OTHERS IN $/BTU

SECTOR I/O CODE	CAPITAL COEFF	OPERATING COEFF
6802	0.0	0.100813E 00
1102	0.284622E-06	0.0
1202	0.0	0.482416E-08
2701	0.120390E-07	0.502973E-09
3612	0.587783E-08	0.245570E-C9
3617	0.995787E-08	0.416029E-09
4006	0.107879E-06	0.450707E-08
4208	0.664280E-07	0.277529E-08
4301	0.281698E-07	0.117689E-08
4502	0.732345E-08	0.305959E-09
4602	0.172383E-07	0.720193E-09
4901	0.289485E-07	0.120942E-08
4903	0.735086E-08	0.307101E-09
4906	0.609174E-07	0.254507E-03
4907	0.313926E-07	0.131155E-08
5305	0.937741E-08	0.391776E-09
5503	0.564726E-07	0.235937E-C8
6202	0.338397E-07	0.141378E-08
6501	0.371805E-08	0.145765E-09
6503	0.538140E-08	0.833040E-10
6504	0.195676E-09	0.145765E-09
6505	0.489214E-09	0.416200E-11
6506	0.0	0.374900E-10
6803	0.0	0.219329E-08
6901	0.240350E-07	0.156529E-08
6902	0.188846E-07	0.276238E-09
7004	0.801290E-08	0.0
7202	0.0	0.154987E-C9
7302	0.0	0.360599E-08
7303	0.442090E-07	0.0
8200	0.0	0.401259E-09

TABLE A-11

NON-ZERO CAPITAL AND OPERATING COEFFICIENTS FOR A
HI GAS

DATA SOURCE: MITRE   VECTOR ORDER: (CAP) 357 & (OP) 357
ENERGY SECTORS IN BTUS/BTU; OTHERS IN $/BTU

SECTOR I/O CODE	CAPITAL COEFF	OPERATING COEFF
3101	0.0	0.106500E-03
900	0.0	0.174901E-07
1102	0.139260E-06	0.0
1202	0.0	0.909656E-08
1601	0.0	0.103062E-09
1602	0.0	0.928400E-11
1706	0.0	0.653900E-11
1708	0.0	0.326300E-11
1804	0.0	0.17625CE-10
1903	0.0	0.190680E-10
2002	0.0	0.140210E-10
2003	0.0	0.169900E-11
2008	0.0	0.267700E-10
2401	0.0	0.427300E-09
2403	0.0	0.696130E-10
2404	0.0	0.216010E-10
2405	0.0	0.960700E-11
2407	0.0	0.432103E-09
2500	0.0	0.177717E-09
2605	0.0	0.540457E-09
2701	0.150761E-07	0.546899E-08
2702	0.0	0.158000E-12
2703	0.0	0.115800E-10
2704	0.0	0.594800E-11
2901	0.0	0.273300E-11
2902	0.0	0.523445E-09
3000	0.0	0.117600E-09
3103	0.0	0.445700E-11
3201	0.0	0.15031CE-10
3203	0.0	0.501100E-11
3204	0.0	0.130295E-09
3501	0.0	0.193910E-10
3601	0.0	0.135100E-11
3608	0.0	0.670000E-12
3612	0.557857E-09	0.0
3613	0.0	0.426000E-10
3617	0.154654E-08	0.0
3619	0.0	0.328400E-10
3701	0.0	0.129857E-09
3704	0.0	0.286090E-10
3801	0.0	0.203900E-10
3802	0.0	0.258137E-09
3803	0.0	0.522250E-10
3805	0.0	0.358110E-10
3806	0.0	0.795700E-11
3807	0.0	0.25000CE-12
3808	0.0	0.119390E-10
3809	0.0	0.609250E-10
3901	0.0	0.108968E-09
3902	0.0	0.129266E-09
4004	0.286199E-07	0.0
4006	0.418744E-06	0.0
4202	0.0	0.174700E-11
4205	0.0	0.264600E-10
4208	0.121554E-06	0.768220E-10
4301	0.526828E-07	0.0
4502	0.267382E-07	0.432755E-09
4602	0.100392E-07	0.163770E-10
4603	0.510450E-08	0.368300E-11
4604	0.0	0.22667CE-10
4703	0.0	0.89674CE-10
4704	0.890764E-09	0.0
4806	0.934447E-09	0.257017E-09
4901	0.117436E-06	0.161918E-09
4903	0.118813E-07	0.0
4906	0.223719E-08	0.227700E-11
4907	0.185630E-07	0.0
5205	0.221166E-07	0.0
5301	0.539811E-09	0.0
5302	0.179879E-08	0.611300E-11
5303	0.329905E-08	0.28800CE-11
5304	0.279621E-07	0.110000E-12
5305	0.169348E-07	0.0
5306	0.137094E-08	0.25600CE-12
5307	0.473592E-08	0.162680E-10
5308	0.225805E-08	0.548000E-12
5501	0.0	0.118410E-10
5502	0.449345E-09	0.0
5503	0.288288E-08	0.213210E-10
5903	0.0	0.157260E-10
6201	0.0	0.134600E-11
6202	0.138540E-07	0.471200E-11
6205	0.0	0.12353CE-10
6301	0.0	0.361600E-11
6302	0.0	0.225000E-12
6303	0.0	0.429800E-11
6401	0.0	0.464500E-11
6407	0.0	0.232000E-11
6412	0.0	0.162500E-10
6501	0.739263E-08	0.174335E-08
6503	0.106999E-07	0.996201E-09
6504	0.389084E-09	0.174336E-08
6505	0.972718E-09	0.498080E--10
6506	0.0	0.448298E-09
6600	0.0	0.918387E-C9
6803	0.0	0.132414E-07
6901	0.367829E-07	0.718825E-09
6902	0.289008E-07	0.126855E-09
7004	0.0	0.231341E-C7
7102	0.280615E-09	0.386596E-08
7202	0.0	0.173467E-09
7301	0.0	0.398060E-08
7302	0.0	0.771081E-09
7303	0.202097E-08	0.820061E-09
7500	0.0	0.181412E-09
7705	0.0	0.107489E-C9
8100	0.0	0.147361E-08
8200	0.0	0.184962E-09

TABLE A-12

NON-ZERO CAPITAL AND OPERATING COEFFICIENTS FOR A LOW GAS REFINERY

DATA SOURCE: B & CAC VECTOR ORDER: (CAP) 90 & (OP) 90
ENERGY SECTORS IN BTUS/BTU; OTHERS IN $/BTU

SECTOR I/O CODE	CAPITAL COEFF	OPERATING COEFF
700	0.0	0.405741E-04
800	0.0	0.998000E-03
3101	0.542165E-03	0.592305E-03
6801	0.100002E-04	0.799224E-03
6802	0.134493E-04	0.189223E-01
200	0.903175E-10	0.0
400	0.715830E-10	0.0
900	0.223574E-09	0.0
1200	0.260997E-10	0.118860E-07
1600	0.241131E-10	0.0
1700	0.934560E-10	0.119809E-09
1800	0.258862E-11	0.0
1900	0.139478E-11	0.0
2000	0.143773E-08	0.0
2200	0.851717E-11	0.0
2300	0.475455E-09	0.0
2400	0.334849E-09	0.224642E-10
2500	0.0	0.499204E-11
2600	0.336430E-11	0.149761E-10
2700	0.829325E-10	0.408848E-08
3000	0.201460E-09	0.222146E-09
3102	0.166279E-09	0.0
3103	0.339442E-09	0.0
3200	0.377595E-09	0.851143E-09
3500	0.385005E-09	0.0
3600	0.876697E-08	0.207170E-08
3700	0.243185E-07	0.298524E-08
3800	0.396575E-08	0.0
4000	0.101937E-06	0.120807E-08
4100	0.570500E-10	0.0
4200	0.176824E-07	0.156001E-08
4300	0.535127E-07	0.121307E-08
4500	0.955090E-08	0.143022E-08
4600	0.753590E-09	0.0
4700	0.345513E-09	0.119809E-09
4900	0.433695E-07	0.213909E-08
5000	0.458037E-10	0.199682E-08
5200	0.135177E-08	0.0
5300	0.190493E-07	0.403357E-08
5400	0.176310E-09	0.0
5500	0.163212E-08	0.624005E-10
5600	0.747980E-10	0.124801E-09
5700	0.0	0.399363E-10
5800	0.540695E-10	0.249602E-11
5900	0.312495E-12	0.0
6200	0.183565E-07	0.232130E-09
6400	0.154346E-09	0.748806E-11
6501	0.383569E-08	0.579076E-09
6503	0.438204E-08	0.451780E-09
6504	0.226155E-09	0.998408E-10
6505	0.263330E-09	0.424323E-10
6506	0.903607E-13	0.773766E-10
6600	0.390268E-09	0.309506E-09
6803	0.168714E-10	0.312002E-09
6900	0.314900E-07	0.327977E-08
7000	0.565595E-09	0.207669E-08
7100	0.658877E-09	0.606308E-07
7300	0.515190E-08	0.603537E-08
7500	0.386750E-09	0.426819E-09
7700	0.884085E-10	0.142273E-09
7800	0.335160E-10	0.157249E-09
7900	0.277677E-10	0.0
8100	0.616014E-09	0.216155E-08
8200	0.332442E-10	0.154753E-09

TABLE A-13

NON-ZERO CAPITAL AND OPERATING COEFFICIENTS FOR A NATURAL GAS UTIL

DATA SOURCE: BATTELLE VECTOR ORDER: (CAP) 90 & (OP) 90
ENERGY SECTORS IN BTUS/BTU: OTHERS IN $/BTU

SECTOR I/O CODE	CAPITAL COEFF	OPERATING COEFF
700	0.0	0.831736E-03
3101	0.0	0.771506E-03
6801	0.0	0.315200E-03
6802	0.0	0.334373E-01
1100	0.141600E-05	0.0
1200	0.0	0.144966E-07
1700	0.504100E-10	0.123137E-09
1800	0.0	0.895544E-10
2000	0.193500E-10	0.0
2200	0.837000E-10	0.0
2300	0.176100E-08	0.0
2400	0.0	0.358217E-09
2600	0.0	0.783601E-10
2700	0.336800E-11	0.0
3200	0.340700E-08	0.391800E-10
3400	0.156900E-10	0.0
3600	0.899700E-11	0.0
3700	0.0	0.111943E-10
3900	0.591800E-12	0.0
4000	0.458000E-07	0.0
4200	0.157000E-07	0.0
4300	0.105100E-07	0.0
4500	0.363200E-07	0.0
4600	0.271700E-07	0.0
4700	0.581200E-08	0.0
4800	0.636600E-08	0.0
4900	0.333400E-07	0.0
5100	0.108700E-07	0.0
5200	0.664400E-08	0.0
5300	0.119200E-06	0.0
5400	0.198600E-11	0.0
5500	0.245500E-08	0.447772E-10
5600	0.538800E-09	0.0
5700	0.593400E-13	0.0
5800	0.481700E-08	0.0
5900	0.385700E-08	0.0
6000	0.783400E-10	0.0
6100	0.119100E-08	0.0
6200	0.246100E-07	0.0
6300	0.183500E-08	0.0
6400	0.164300E-07	0.0
6501	0.316900E-08	0.951515E-10
6503	0.604300E-08	0.615686E-10
6504	0.828100E-10	0.223886E-10
6505	0.669200E-10	0.0
6506	0.0	0.111943E-10
6507	0.224300E-09	0.0
6600	0.0	0.186385E-08
6803	0.0	0.347023E-09
6900	0.472900E-07	0.156720E-08
7000	0.0	0.339747E-08
7100	0.0	0.389561E-08
7200	0.0	0.100749E-08
7300	0.0	0.586581E-08
7500	0.0	0.151123E-09
7700	0.0	0.263066E-09
7800	0.0	0.212132E-08
7900	0.0	0.182971E-07
8100	0.0	0.283216E-08
8200	0.0	0.414189E-09

TABLE A-14

NON-ZERO CAPITAL AND OPERATING COEFFICIENTS FOR A COAL POWER PLANT

DATA SOURCE: B & CAC   VECTOR ORDER: (CAP) 90 & (OP) 101
ENERGY SECTORS IN BTUS/BTU; OTHERS IN $/BTU

SECTOR I/O CODE	CAPITAL COEFF	OPERATING COEFF
3101	0.337044E-01	
6801	0.420403E-04	
6802	0.565404E-04	
FOS ELEC		0.871577E-01
OTH FEED		0.498236E-04
MOTIVE		0.980569E-03
WATER HT		0.581098E-03
SPACE HT		0.130572E-01
A/C		0.896705E-03
ELEC POW		0.426376E-02
200	0.379691E-09	0.0
400	0.300931E-09	0.0
500	0.0	0.723983E-10
600	0.0	0.168930E-09
900	0.939895E-09	0.241327E-10
1000	0.0	0.241327E-10
1200	0.109722E-09	0.193335E-06
1300	0.0	0.482654E-10
1400	0.0	0.361991E-09
1500	0.0	0.723983E-10
1600	0.101370E-09	0.434389E-09
1700	0.392886E-09	0.530906E-09
1800	0.108824E-10	0.142694E-08
1900	0.586360E-11	0.0
2000	0.447716E-07	0.217190E-09
2200	0.358057E-10	0.241327E-10
2300	0.199879E-08	0.0
2400	0.140769E-08	0.571931E-08
2500	0.0	0.627451E-09
2600	0.141434E-10	0.134691E-08
2700	0.201439E-08	0.136749E-08
2800	0.0	0.506788E-09
2900	0.0	0.242798E-10
3000	0.489337E-08	0.241322E-10
3102	0.699029E-09	0.0
3103	0.142700E-08	0.0
3200	0.917159E-08	0.475402E-08
3300	0.0	0.241327E-10
3500	0.161855E-08	0.0
3600	0.783920E-07	0.168930E-09
3700	0.321024E-07	0.518854E-08
3800	0.768758E-07	0.263041E-08
4000	0.165088E-05	0.0
4100	0.239836E-09	0.0
4200	0.109803E-06	0.408756E-08
4300	0.876756E-06	0.410256E-09
4400	0.0	0.217195E-09
4500	0.177615E-06	0.0
4600	0.714574E-07	0.0
4900	0.172893E-06	0.663045E-08
5000	0.192558E-09	0.241327E-10
5200	0.375343E-07	0.0
5300	0.212976E-06	0.877158E-08
5400	0.741199E-09	0.0
5500	0.686135E-08	0.678112E-08
5600	0.314447E-09	0.265460E-09
5700	0.0	0.566335E-09
5800	0.227306E-09	0.193057E-09
5900	0.131372E-11	0.651567E-09
6200	0.728826E-07	0.0
6300	0.0	0.241327E-10
6400	0.648864E-09	0.241322E-10
6501	0.515560E-07	0.118411E-06
6503	0.411548E-07	0.302595E-07
6504	0.880495E-09	0.155480E-07
6505	0.394486E-08	0.841340E-10
6506	0.561740E-11	0.267495E-09
6600	0.164067E-08	0.136754E-07
6803	0.709268E-10	0.380692E-08
6900	0.355360E-06	0.384695E-07
7000	0.237774E-08	0.299605E-07
7100	0.276990E-08	0.111342E-07
7200	0.0	0.484657E-08
7300	0.216584E-07	0.384139E-07
7500	0.162588E-08	0.796180E-08
7700	0.371666E-09	0.169878E-08
7800	0.140900E-09	0.125479E-07
7900	0.116734E-09	0.555038E-08
8100	0.258970E-08	0.160138E-07
8200	0.139757E-09	0.466677E-08

TABLE A-15

NON-ZERO CAPITAL AND OPERATING COEFFICIENTS FOR A OIL POWER PLANT

DATA SOURCE: B & CAC   VECTOR ORDER: (CAP) 90 & (OP) 101
ENERGY SECTORS IN BTUS/BTU; OTHERS IN $/BTU

SECTOR I/O CODE	CAPITAL COEFF	OPERATING COEFF
3101	0.517669E-01	
6801	0.263920E-04	
6802	0.354949E-04	
FOS ELEC		0.871577E-01
OTH FEED		0.498236E-04
MOTIVE		0.980569E-03
WATER HT		0.581098E-03
SPACE HT		0.130572E-01
A/C		0.896705E-03
ELEC POW		0.426376E-02
200	0.238362E-09	0.0
400	0.188918E-09	0.0
500	0.0	0.723983E-10
600	0.0	0.168930E-09
900	0.590045E-09	0.241327E-10
1000	0.0	0.241327E-10
1200	0.688809E-10	0.193335E-06
1300	0.0	0.482654E-10
1400	0.0	0.361991E-09
1500	0.0	0.723983E-10
1600	0.636381E-10	0.434389E-09
1700	0.246644E-09	0.530906E-09
1800	0.683175E-11	0.142694E-08
1900	0.368103E-11	0.0
2000	0.145507E-07	0.217190E-09
2200	0.224781E-10	0.241327E-10
2300	0.125479E-08	0.0
2400	0.883715E-09	0.571931E-08
2500	0.0	0.627451E-09
2600	0.887891E-11	0.134691E-08
2700	0.348645E-09	0.136749E-08
2800	0.0	0.506788E-09
2900	0.0	0.242798E-10
3000	0.846930E-09	0.241322E-10
3102	0.438834E-09	0.0
3103	0.895840E-09	0.0
3200	0.158739E-08	0.475402E-08
3300	0.0	0.241327E-10
3500	0.101609E-08	0.0
3600	0.561615E-07	0.168930E-09
3700	0.503760E-07	0.518854E-08
3800	0.392097E-07	0.263041E-08
4000	0.112171E-05	0.0
4100	0.150564E-09	0.0
4200	0.872110E-07	0.408756E-08
4300	0.869560E-06	0.410256E-09
4400	0.0	0.217195E-09
4500	0.189883E-06	0.0
4600	0.228804E-07	0.0
4900	0.984968E-07	0.663045E-08
5000	0.120883E-09	0.241327E-10
5200	0.841890E-08	0.0
5300	0.131411E-06	0.877158E-08
5400	0.465307E-09	0.0
5500	0.430740E-08	0.678112E-08
5600	0.197403E-09	0.265460E-09
5700	0.0	0.566335E-09
5800	0.142698E-09	0.193057E-09
5900	0.824724E-12	0.651567E-09
6200	0.471594E-07	0.0
6300	0.0	0.241327E-10
6400	0.407343E-09	0.241322E-10
6501	0.421843E-07	0.118411E-06
6503	0.302447E-07	0.302595E-07
6504	0.788006E-09	0.155480E-07
6505	0.260700E-08	0.841340E-10
6506	0.862784E-11	0.267495E-09
6600	0.102998E-08	0.136754E-07
6803	0.445263E-10	0.380692E-08
6900	0.244887E-06	0.384695E-07
7000	0.149269E-08	0.299605E-07
7100	0.173888E-08	0.111342E-07
7200	0.0	0.484657E-08
7300	0.135966E-07	0.384139E-07
7500	0.102069E-08	0.796180E-08
7700	0.233323E-09	0.169878E-08
7800	0.884540E-10	0.125479E-07
7900	0.732833E-10	0.555038E-08
8100	0.162576E-08	0.160138E-07
8200	0.877364E-10	0.466677E-08

TABLE A-16

NON-ZERO CAPITAL AND OPERATING COEFFICIENTS FOR A HI GAS POWER PLT

DATA SOURCE: B & CAC VECTOR ORDER: (CAP) 90 & (OP) 101
ENERGY SECTORS IN BTUS/BTU; OTHERS IN $/BTU

SECTOR I/O CODE	CAPITAL COEFF	OPERATING COEFF
3101	0.428287E-02	
6801	0.154148E-04	
6802	0.207315E-04	
FOS ELEC		0.871577E-01
OTH FEED		0.498236E-04
MOTIVE		0.980569E-03
WATER HT		0.581098E-03
SPACE HT		0.130572E-01
A/C		0.896705E-03
ELEC POW		0.426376E-02
200	0.139220E-09	0.0
400	0.110342E-09	0.0
500	0.0	0.723983E-10
600	0.0	0.168930E-09
900	0.344628E-09	0.241327E-10
1000	0.0	0.241327E-10
1200	0.402313E-10	0.193335E-06
1300	0.0	0.482654E-10
1400	0.0	0.361991E-09
1500	0.0	0.723983E-10
1600	0.371692E-10	0.434389E-09
1700	0.144058E-09	0.530906E-09
1800	0.399023E-11	0.142694E-08
1900	0.214998E-11	0.0
2000	0.962588E-08	0.217190E-09
2200	0.131288E-10	0.241327E-10
2300	0.732890E-09	0.0
2400	0.516153E-09	0.571931E-08
2500	0.0	0.627451E-09
2600	0.518592E-11	0.134691E-08
2700	0.774767E-10	0.136749E-08
2800	0.0	0.506788E-09
2900	0.0	0.242798E-10
3000	0.188207E-09	0.241322E-10
3102	0.256310E-09	0.0
3103	0.523234E-09	0.0
3200	0.352753E-09	0.475402E-08
3300	0.0	0.241327E-10
3500	0.593467E-09	0.0
3600	0.146254E-07	0.168930E-09
3700	0.113593E-07	0.518854E-08
3800	0.138932E-07	0.263041E-08
4000	0.634886E-06	0.0
4100	0.879397E-10	0.0
4200	0.247786E-07	0.408756E-08
4300	0.852895E-06	0.410256E-09
4400	0.0	0.217195E-09
4500	0.733324E-07	0.0
4600	0.844815E-08	0.0
4900	0.272438E-07	0.663045E-08
5000	0.706044E-10	0.241327E-10
5200	0.105236E-08	0.0
5300	0.564365E-07	0.877158E-08
5400	0.271772E-09	0.0
5500	0.251583E-08	0.678112E-08
5600	0.115297E-09	0.265460E-09
5700	0.0	0.566335E-09
5800	0.833454E-10	0.193057E-09
5900	0.481697E-12	0.651567E-09
6200	0.187079E-07	0.0
6300	0.0	0.241327E-10
6400	0.237917E-09	0.241322E-10
6501	0.190442E-07	0.118411E-06
6503	0.139140E-07	0.302595E-07
6504	0.283425E-09	0.155480E-07
6505	0.140321E-08	0.841340E-10
6506	0.713813E-12	0.267495E-09
6600	0.601580E-09	0.136754E-07
6803	0.260065E-10	0.380692E-08
6900	0.116761E-06	0.384695E-07
7000	0.871835E-09	0.299605E-07
7100	0.101563E-08	0.111342E-07
7200	0.0	0.484657E-08
7300	0.794141E-08	0.384139E-07
7500	0.596155E-09	0.796180E-08
7700	0.136277E-09	0.169878E-08
7800	0.516633E-10	0.125479E-07
7900	0.428027E-10	0.555038E-08
8100	0.949556E-09	0.160138E-07
8200	0.512443E-10	0.466677E-08

TABLE A-17

NON-ZERO CAPITAL AND OPERATING COEFFICIENTS FOR A CCC

DATA SOURCE: MITRE VECTOR ORDER: (CAP) 357 & (OP) 357
ENERGY SECTORS IN BTUS/BTU: OTHERS IN $/BTU

SECTOR I/O CODE	CAPITAL COEFF	OPERATING COEFF
3101	0.0	0.625000E-03
6801	0.0	0.148375E 00
1102	0.859199E-06	0.0
1105	0.151398E-06	0.0
1202	0.0	0.651746E-07
1601	0.0	0.160556E-09
1602	0.0	0.149080E-10
1706	0.0	0.968800E-11
1708	0.0	0.537600E-11
1804	0.0	0.288130E-10
1903	0.0	0.304880E-10
2002	0.0	0.246040E-10
2003	0.0	0.284000E-11
2008	0.0	0.474300E-11
2301	0.683960E-10	0.0
2302	0.683960E-10	0.0
2305	0.683960E-10	0.0
2307	0.455971E-09	0.0
2401	0.0	0.683113E-09
2403	0.0	0.111400E-09
2404	0.0	0.349010E-10
2405	0.0	0.154720E-10
2407	0.0	0.690317E-09
2500	0.0	0.291387E-09
2605	0.0	0.368442E-09
2701	0.0	0.756860E-10
2704	0.0	0.963900E-11
2901	0.0	0.416000E-11
2902	0.0	0.520294E-08
3000	0.0	0.192262E-09
3103	0.0	0.760900E-11
3201	0.0	0.238420E-10
3203	0.0	0.771000E-11
3204	0.0	0.210321E-09
3501	0.0	0.327710E-10
3601	0.0	0.182000E-11
3608	0.0	0.912000E-12
3613	0.0	0.720350E-10
3617	0.487160E-07	0.0
3619	0.0	0.535190E-10
3621	0.939803E-08	0.0
3701	0.0	0.221279E-09
3704	0.0	0.484460E-10
3801	0.0	0.299820E-10
3802	0.0	0.387316E-09
3803	0.0	0.778170E-10
3804	0.0	0.178060E-10
3805	0.0	0.534180E-10
3806	0.0	0.122260E-10
3807	0.0	0.354000E-12
3809	0.0	0.909030E-10
3810	0.139196E-07	0.0
3901	0.0	0.186835E-09
3902	0.0	0.222294E-09
4006	0.486520E-06	0.0
4202	0.188315E-08	0.273900E-11
4205	0.199079E-08	0.146577E-08
4208	0.178128E-06	0.127380E-09
4301	0.383333E-06	0.0
4302	0.332594E-06	0.0
4502	0.672390E-08	0.0
4602	0.183883E-07	0.267850E-10
4603	0.815729E-09	0.593600E-11
4604	0.0	0.377410E-10
4702	0.142082E-08	0.0
4703	0.0	0.145185E-09
4806	0.0	0.425563E-09
4901	0.138704E-06	0.271450E-09
4903	0.692393E-08	0.0
4905	0.522789E-08	0.0
4906	0.906568E-08	0.380600E-11
4907	0.479080E-08	0.0
5101	0.968030E-08	0.0
5102	0.901949E-10	0.0
5104	0.601750E-10	0.0
5301	0.119123E-07	0.0
5302	0.510809E-07	0.297240E-09
5303	0.734224E-07	0.293100E-10
5304	0.320499E-06	0.0
5305	0.157223E-07	0.0
5306	0.0	0.406000E-12
5307	0.0	0.171650E-09
5308	0.415172E-08	0.117230E-09
5501	0.0	0.196830E-10
5503	0.136034E-06	0.355100E-10
5604	0.150131E-08	0.0
5903	0.0	0.263800E-10
6201	0.252839E-09	0.293080E-09
6202	0.337835E-07	0.152070E-09
6203	0.406359E-09	0.146540E-09
6205	0.0	0.203410E-10
6301	0.0	0.542800E-11
6302	0.0	0.356000E-12
6303	0.0	0.634100E-11
6401	0.0	0.771000E-11
6407	0.0	0.385500E-11
6412	0.527808E-09	0.269380E-10
6501	0.140158E-07	0.167191E-08
6503	0.202861E-07	0.543300E-10
6504	0.737705E-09	0.951170E-10
6505	0.184421E-08	0.273900E-11
6506	0.0	0.244510E-10
6600	0.0	0.288909E-08
6803	0.0	0.125913E-07
6901	0.751748E-07	0.159894E-07
6902	0.590658E-07	0.101145E-08
7004	0.868077E-07	0.120572E-07
7102	0.0	0.256526E-08
7202	0.0	0.128242E-09
7301	0.0	0.265921E-08
7302	0.0	0.518042E-09
7303	0.403490E-06	0.558272E-09
7500	0.0	0.128090E-09
7705	0.0	0.809630E-10
8100	0.0	0.406282E-08
8200	0.0	0.959350E-09

TABLE A-18

NON-ZERO CAPITAL AND OPERATING COEFFICIENTS FOR A LWR

DATA SOURCE: MITRE   VECTOR ORDER: (CAP) 357 & (OP) 357
ENERGY SECTORS IN BTUS/BTU; OTHERS IN $/BTU

ECTOR I/O CODE	CAPITAL COEFF	OPERATING COEFF
3101	0.158600E-02	0.106400E-02
6801	0.117800E-04	0.900000E-01
207	0.526120E-10	0.0
400	0.571290E-10	0.0
900	0.322320E-09	0.0
1102	0.173936E-05	0.0
1202	0.0	0.169650E-08
1804	0.0	0.928359E-09
2001	0.289410E-10	0.0
2002	0.423194E-09	0.0
2006	0.259420E-09	0.0
2008	0.109146E-08	0.0
2009	0.554970E-10	0.0
2302	0.139145E-08	0.0
2304	0.222617E-09	0.0
2305	0.605641E-08	0.0
2307	0.347869E-08	0.0
2406	0.496420E-10	0.0
2605	0.0	0.510016E-09
2701	0.0	0.119711E-07
2704	0.606000E-10	0.0
3000	0.129819E-08	0.0
3102	0.320564E-09	0.0
3203	0.213037E-09	0.0
3204	0.448664E-09	0.0
3501	0.406510E-10	0.0
3601	0.190916E-09	0.0
3605	0.391117E-09	0.0
3608	0.383966E-09	0.0
3610	0.665800E-10	0.0
3611	0.121609E-08	0.0
3612	0.123834E-08	0.0
3617	0.141560E-07	0.0
3619	0.377650E-10	0.0
3620	0.555390E-10	0.0
3621	0.393961E-09	0.0
3702	0.133169E-08	0.0
3807	0.111790E-09	0.0
3810	0.480553E-07	0.0
4004	0.379828E-07	0.0
4005	0.364309E-09	0.0
4006	0.490421E-06	0.391326E-08
4007	0.658316E-09	0.0
4008	0.222617E-09	0.0
4009	0.774748E-09	0.0

SECTOR I/O CODE	CAPITAL COEFF	OPERATING COEFF
4101	0.766169E-10	0.0
4202	0.167178E-08	0.0
4203	0.511731E-09	0.0
4205	0.501485E-09	0.0
4208	0.435363E-06	0.423386E-08
4211	0.211091E-08	0.0
4301	0.509464E-06	0.0
4501	0.370960E-10	0.0
4601	0.442890E-10	0.0
4603	0.246877E-07	0.0
4806	0.127613E-06	0.907695E-08
4901	0.219779E-06	0.0
4906	0.864476E-07	0.0
4907	0.494901E-07	0.373359E-08
5000	0.330390E-10	0.0
5101	0.578229E-07	0.0
5203	0.843540E-10	0.0
5301	0.100072E-07	0.0
5302	0.500947E-07	0.0
5303	0.711331E-07	0.0
5304	0.783273E-07	0.0
5305	0.948049E-07	0.509317E-08
5502	0.561248E-09	0.0
5503	0.823617E-07	0.0
5601	0.182510E-09	0.0
5604	0.142625E-08	0.0
5702	0.136899E-08	0.260202E-08
5805	0.404420E-10	0.0
6202	0.116600E-06	0.444494E-08
6411	0.381000E-10	0.0
6412	0.318933E-09	0.0
6501	0.247608E-07	0.713508E-08
6503	0.429350E-07	0.203856E-08
6504	0.136602E-08	0.815399E-09
6505	0.318523E-08	0.101961E-09
6506	0.0	0.101961E-09
6600	0.280624E-09	0.914391E-09
6803	0.0	0.768328E-08
6901	0.137171E-06	0.105459E-07
6902	0.107480E-06	0.186103E-08
7001	0.129313E-09	0.0
7004	0.277069E-09	0.118190E-07
7102	0.485132E-09	0.126130E-08
7202	0.0	0.164924E-08
7301	0.109841E-08	0.304688E-08
7302	0.991180E-10	0.0
7303	0.0	0.652160E-08
7500	0.304922E-09	0.644470E-10
7703	0.0	0.156380E-08
7705	0.654089E-10	0.0
7801	0.230020E-10	0.171636E-09
7903	0.240060E-10	0.0
8100	0.475053E-09	0.119263E-08
8200	0.242692E-09	0.266321E-08

TABLE A-19

NON-ZERO CAPITAL AND OPERATING COEFFICIENTS FOR A HTGR

DATA SOURCE: MITRE VECTOR ORDER: (CAP) 357 & (OP) 357
ENERGY SECTORS IN BTUS/BTU: OTHERS IN $/BTU

SECTOR I/O CODE	CAPITAL COEFF	OPERATING COEFF
3101	0.276000E-02	0.945000E-03
6801	0.212300E-04	0.900000E-01
207	0.642390E-10	0.0
400	0.101522E-09	0.0
900	0.661467E-09	0.0
1102	0.268388E-05	0.0
1202	0.0	0.354587E-08
1601	0.365220E-10	0.0
1709	0.220650E-10	0.0
1804	0.0	0.101935E-08
2001	0.310330E-10	0.0
2002	0.653157E-09	0.0
2006	0.130484E-08	0.0
2008	0.168462E-08	0.0
2009	0.856520E-10	0.0
2302	0.193299E-08	0.0
2305	0.371413E-09	0.0
2406	0.961960E-10	0.0
2407	0.106250E-09	0.0
2605	0.0	0.828478E-09
2701	0.0	0.142483E-07
2801	0.466413E-09	0.0
3000	0.221000E-08	0.0
3102	0.522826E-09	0.0
3203	0.232174E-09	0.0
3204	0.920815E-09	0.0
3501	0.827169E-10	0.0
3601	0.379837E-09	0.0
3605	0.778152E-09	0.0
3608	0.763967E-09	0.0
3610	0.132500E-09	0.0
3611	0.241951E-08	0.0
3612	0.241846E-07	0.0
3617	0.874511E-09	0.0
3618	0.293252E-07	0.0
3619	0.194506E-06	0.0
3620	0.110704E-06	0.0
3621	0.783804E-09	0.0
3701	0.260759E-06	0.0
3702	0.290022E-08	0.0
3807	0.221848E-09	0.0
3810	0.151202E-06	0.0
4001	0.854331E-08	0.0
4003	0.392475E-07	0.0
4004	0.555245E-07	0.0
4005	0.730924E-09	0.0
4006	0.312777E-06	0.488190E-08
4007	0.131990E-08	0.0
4008	0.446630E-09	0.0
4009	0.155333E-08	0.0
4101	0.147826E-09	0.0
4202	0.733592E-08	0.0
4203	0.122120E-09	0.0
4205	0.377126E-07	0.0
4208	0.479242E-06	0.531858E-08
4211	0.264457E-09	0.0
4301	0.548920E-06	0.0
4501	0.732610E-10	0.0
4601	0.891300E-10	0.0
4602	0.244157E-08	0.0
4603	0.113390E-06	0.0
4604	0.159297E-07	0.0
4806	0.149175E-06	0.117956E-07
4901	0.248733E-06	0.0
4903	0.159141E-08	0.0
4906	0.102976E-07	0.0
4907	0.402478E-06	0.446369E-08
5000	0.656519E-10	0.0
5101	0.933638E-07	0.0
5203	0.222567E-07	0.0
5205	0.412429E-08	0.0
5301	0.463310E-08	0.0
5302	0.858220E-07	0.0
5303	0.731044E-07	0.0
5304	0.333162E-06	0.0
5305	0.623037E-07	0.626570E-08
5308	0.156642E-07	0.0
5404	0.378800E-10	0.0
5502	0.111446E-08	0.0
5503	0.364256E-07	0.0
5601	0.568967E-09	0.0
5604	0.117261E-08	0.0
5702	0.819402E-08	0.409706E-08
5805	0.839130E-10	0.0
6202	0.148104E-06	0.546820E-08
6203	0.717929E-10	0.0
6411	0.769020E-10	0.0
6412	0.468641E-09	0.0
6501	0.366275E-07	0.844999E-08
6503	0.632133E-07	0.241429E-08
6504	0.199592E-08	0.965707E-09
6505	0.473032E-08	0.120707E-09
6506	0.0	0.120707E-09
6600	0.543696E-09	0.118826E-08
6803	0.0	0.868217E-08
6901	0.183907E-06	0.127229E-07
6902	0.144169E-06	0.224522E-08
7001	0.234185E-09	0.0
7004	0.538587E-09	0.150414E-07
7102	0.949946E-09	0.143418E-08
7202	0.0	0.214321E-08
7301	0.224456E-08	0.373951E-08
7302	0.202500E-09	0.0
7303	0.0	0.967141E-08
7500	0.611413E-09	0.120598E-09
7703	0.0	0.186549E-08
7705	0.123098E-09	0.0
7801	0.467930E-10	0.223043E-09
7903	0.444570E-10	0.0
8100	0.894674E-09	0.146125E-08
8200	0.457070E-10	0.422994E-08

IBLIOGRAPHIC DATA HEET

1. Report No.
UIUC-CAC-DN-75-165

2.

3. Recipient's Accession No.

Title and Subtitle
TOTAL ENERGY REQUIREMENTS FOR NINE ELECTRICITY-GENERATING SYSTEMS

5. Report Date
August 1975

6.

Author(s)
David A. Pilati and Ralph P. Richard

8. Performing Organization Rept. No.
CAC 165

Performing Organization Name and Address
Center for Advanced Computation
University of Illinois at Urbana-Champaign
Urbana, Illinois 61801

10. Project/Task/Work Unit No.

11. Contract/Grant No.
NSF SIA72-03530

2. Sponsoring Organization Name and Address
National Science Foundation
1800 G. Street
Washington, D. C. 20301

13. Type of Report & Period Covered
Research

14.

Supplementary Notes
None

Abstracts

Using the CAC energy-employment policy model, a methodology is developed to compute the total energy requirements for complete energy supply systems. The capital and operating requirements of 16 separate energy supply facilities are used to evaluate the total energy required by nine alternative means of producing and delivering electricity. The evaluated electricity-generating systems rely on either coal, oil, natural gas, or nuclear energy as their fuel source. Each system is a net energy sink for some time after operation commences. However, in less than two-thirds of a year each system produces more electricity than would have been produced if the energy requirements (other than fuel) had been diverted to existing electricity-generating systems. Lack of data precluded the inclusion of all transportation-related requirements. Energy payback periods could be more than doubled if these requirements were included.

Key Words and Document Analysis. 17a. Descriptors
Energy
Energy-employment policy model
Energy supply systems
Electricity

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

Availability Statement No restriction on distribution.
Available from National Technical Information Service, Springfield, Virginia 22151

19. Security Class (This Report)
UNCLASSIFIED

20. Security Class (This Page
UNCLASSIFIED

21. No. of Pages
56

22. Price

RM NTIS-35 (REV. 3-72)

USCOMM-DC 14952-P72