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VOLUME I. MODEL STRUCTURE AND USE

BECHTEL CORPORATION

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THE ENERGY SUPPLY PLANNING MODEL

Volume I: Model Structure and Use

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San Francisco, California**

August 1975

**Final Report to
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Abstract

The specific modeling work reported here was stimulated by the need to explore the feasibility of proposed U.S. energy policies in terms of the requirements for specific societal resources associated with the construction and operation of energy supply and energy transportation facilities needed to implement these energy supply policies.

The Energy Supply Planning Model is designed to convert future (1975 to 1995) energy mixes to resource requirements schedules. With this planning tool, the feasibility of various proposed mixes can be assessed in terms of the time, capital, manpower, materials, and construction schedules required for the specified energy supply system.

In carrying out the modeling efforts, special emphasis was placed on developing a rather transparent planning model where the user can test the implications of different energy policy options.

A second criterion in developing the structure of the model was to respond to the need for flexibility. The model should be useful both to the policy maker and to the policy analyst. This flexibility was accomplished by providing the ability to derive model results by specifying inputs at various levels of detail to obtain results in various levels of resolution.

The major usefulness of the model is expected to lie in its capability to explore the feasibility of various energy policies, their implications, and their desirability.

PREFACE

In late 1973, a growing national perception of the degree of U. S. dependence on foreign oil supplies stimulated the proposal of several U.S. energy policies. These policies were generally aimed at reducing, or at least varying, demand for specific energy forms and devising different schemes to supply sufficient energy from domestic resources at the earliest possible date. To compare and evaluate these proposals, Dr. Raymond L. Zahradnik, then with the Office of Energy R&D Policy of the National Science Foundation, prompted us to think of a means for converting the proposed policies into strategies and programs that would establish, primarily, "critical path facilities" and, in so doing, would make possible judgments on the feasibility of the proposed policies.

After some reflection on the complexities of an undertaking of this kind, it was decided to generate a consistent means of converting proposed U.S. energy supply policies to annual schedules of facilities and the capital, manpower, and material resources required to bring them on-line. This, it was believed, would constitute the first step toward determining the feasibility of proposed policies.

The first phase of the study, then, was designed to develop and demonstrate the methodology that such a planning tool would employ and to explore the categories of materials and manpower that would yield information to help to assess feasibility. The first phase was successfully completed in July 1974, and the results are contained in a two-volume report entitled: Path to Self Sufficiency - Directions and Constraints, available from the National Technical Information Service. At the conclusion of that effort, the second phase of study under the same contract was

designed to use the basic methodology as developed but to expand substantially the categories and number of resources treated, as well as to develop a regional disaggregation modeling capability and extend the time horizon to 1995.

This report documents the whole study making no distinction between the two phases. The structure and function of the Energy Supply Planning Model are described and its use illustrated. Both the modeling effort and the development of the supporting data base are at a point where the model may be used intelligently for energy supply planning. It is anticipated, nevertheless, that work on this model will continue, if for no other reason, simply because of the dynamic nature of our perception of significant information categories relevant to the synthesis of energy supply options with other policies.

MC, July 1975

ACKNOWLEDGEMENTS

This study was sponsored by the National Science Foundation, Office of Energy R&D Policy. The study was initiated after a series of discussions with Dr. Raymond L. Zahradnik who first perceived the need for a planning model and who, subsequent to the initiation of the study, provided continual encouragement.

Dr. Paul Donovan and Dr. Paul Craig of NSF-OEP contributed periodical and timely forums for review. Special thanks go to Dr. Fred Orthlieb, of the same office, who helped by providing a reliable link between the methodological and operational aspects of the study and matters of administration.

The study was performed by the Energy Systems Group of Bechtel Corporation under the direction of Dr. Meir Carasso, who was the project manager of the study from its inception. Dr. J. Michael Gallagher, also with the project from its inception, in his capacity as project engineer and principal investigator, was responsible for the performance of many of the methodological tasks and at present has overall technical responsibility for the effort. Dr. Kishandutt J. Sharma developed the area of user access to decision variables and consulted in the initial formulation of several aspects of the technical approach. Dr. Ronald Barany was responsible for all systems programming.

Many people contributed to the development of data for this study: Mr. John Gayle was responsible for data development within Bechtel; special credit is due those people within the Bechtel Operating Divisions who contributed to the development of the data base for construction resource

requirements; Dr. Ed Kinderman and Dr. Steve Kohan headed the development of the operations resource requirements at SRI (under a subcontract to Bechtel). The timely delivery of good operating data materially improved the total effort.

Other contributors from Bechtel include: Mr. Leon Olver - transportation systems analysis, Messrs. Paul F. Paskert, Robert J. Walcott, and Tom Cassel - data development support, and Ms. Barbara A. F. Miller and Mr. Steven Shantzis - regional model technical support. The work also benefited by formal and informal contributions from many reviewers too numerous to list; particularly the support of Ms. Carol McKeown and Mr. Ghassan Khoury are acknowledged.

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Section 1

INTRODUCTION AND SUMMARY

BACKGROUND

Several years have passed since the emergence of global resource scarcity as an issue of vital concern to us, and one that has potentially serious implications on the well-being of future generations. Large geopolitical differences between the location of energy resources and the location of large energy demand centers are creating globally significant changes in historical supply-demand patterns and forcing realignments of relationships. Concern with the availability and price of energy resources is stimulating a major rethinking of attitudes, policies, and institutions on an international scale. The questions raised are global in nature with geopolitical, demographic, resource, economic, and technical aspects.

The sudden awareness of the extent of U.S. (and other developed countries) dependence on overseas oil has set off a belated examination of both near- and long-term energy resources and supply options. Although it is startling, in retrospect, that these problems are only now being addressed, they have become the serious preoccupation of government, academia, industry, and many other institutions. Research and studies of these topics are marked by a rapid increase in interdisciplinary modeling activity.

The specific modeling work reported here was stimulated by the need to explore the feasibility of proposed U.S. energy policies in terms of the

requirements for specific societal resources associated with the construction and operation of energy supply and energy transportation facilities needed to implement these energy supply policies.

Because of possible constraints on foreign supplies, several candidate energy policies for the near- and mid-term have been proposed; all of them emphasize conservation and the additional, expeditious development of domestic energy resources. The proposed energy policies that emerged differ in the degrees of emphasis placed on conservation and alternative energy sources such as oil shale, geothermal power, offshore oil, nuclear power, etc. Consequently, building the necessary energy supply facilities for each mix requires a different combination of the country's capital, manpower, and material resources.

FUNCTION AND METHOD

The Energy Supply Planning Model is designed to convert future (1975 to 1995) energy mixes to resource requirements schedules. With this planning tool, the feasibility of various proposed mixes can be assessed in terms of the time, capital, manpower, materials, and construction schedules required for the candidate energy supply system.

The model is basically a systematic planning method, and its operation proceeds as follows:

1. The user chooses a candidate future energy mix of interest, typically for the years 1975 or 1977, 1980, 1985, and 1990.
2. A computer program then calculates, by year, the number of new energy facilities of various types that must be brought onstream and operated to meet that specified mix. These facilities are additional to those extant on January 1, 1974.

3. Employing user specifications, and at user option, the model locates the facilities in one of 14 regions in the U.S., allocates fuels derived from the facilities to the demand of the 11 land regions, and calculates transportation facilities required to accomplish this distribution. ✓
4. The program next calculates separately the annual requirements of capital, manpower, and material for each energy and transportation facility from initial commitment to plant startup and for operation throughout its economic life. (These requirements are expressed without regard to the availability of such resources.)
5. The program then tabulates an annual regional schedule of required energy and transportation facilities to be brought on-line and attendant annual schedules of capital, manpower, and material requirements for the energy supply system as a whole and, if so desired, individual facilities.

User Options

In carrying out the modeling efforts, special emphasis was placed on developing a rather transparent planning model where the user can test the implications of different energy policy options.

A second criterion in developing the structure of the model was to respond to the need for flexibility. The model should be useful both to the policy maker and to the policy analyst. This flexibility was accomplished by providing the ability to specify inputs at various levels of detail and to obtain results in corresponding levels of resolution.

The major usefulness of the model is expected to be in its capability to help explore the feasibility of various energy policies, their implications, and their desirability. This capability is outlined in the following list of questions which the model may either answer or help answer.

Some Questions the Model Answers Explicitly

- What energy facilities must be constructed to implement a candidate national energy development program?
- When would they need to be on-line? Committed?
- What direct capital, manpower, and materials would be needed? When?
- What resources would be required to operate these facilities?
- What would be the requirements of a specific energy industry? (e.g., what will be the manpower requirements of the coal industry in 1983?)
- What would be the requirements in a specific region of the country?
- What would be the transportation requirements of a candidate national energy program?

Some Questions the Model Can Be Helpful in Answering

- How different are the requirements of different energy programs? What are the regional implications of the differences?
- Is a given energy program feasible? If not, what can be done to make it feasible?
- Which capital, manpower, and materials resource categories are potential bottlenecks?
- What would be the indirect and total requirements of a candidate energy program?
- What is the gross energy efficiency of the resulting system?

Some Questions the Model Does Not Answer

- What should be our national energy program?
- What should be our national resources program?
- What should be our national energy imports program?

MODEL APPLICATION AND SAMPLE RESULTS **

The model has been applied to the President's Energy Program for the purpose of demonstrating the types of information that can be generated by the model from a set of input specifications.

The details of this model application, as well as the use of the model to trace the effects of various energy policy options on these information categories, are presented in Sections 7 and 8 of this report.

Summary Description of the President's Energy Program

Salient characteristics of the President's energy program are summarized in Tables 1-1, 1-2, and 1-3. Annual growth rates for the 1973 to 1985 period of approximately 2.5 percent per year for total energy consumption and 6.5 percent per year for electric generation capacity are envisioned by the President's program. Major increases are targeted for the consumption of coal and nuclear fuels, along with modest increases for oil, hydroelectric power, and geothermal power, while consumption of natural gas is expected to decline. Table 1-3 presents the fuel mix in physical units.

Table 1-1

FUELS FOR TOTAL ENERGY SYSTEM⁽¹⁾ (10¹⁵ Btu)

Fuel	1973 (Actual)	1985
Coal	13.1	23.3
Oil	34.4	40.8
Gas	23.5	20.1
Nuclear	1.3	12.5
Geothermal and hydro	3.1	4.8
Total	75.4	101.5

ERO4-77
SF-2

20.86

40.5

24.34

7.89

4.2

97.97

Solar also

Note: (1) Source: FEA, "Draft Environmental Impact Statement of the Energy Independence Act of 1975" (DEIS), March 1975 (most values)

Table 1-2

ELECTRIC POWER GENERATION⁽¹⁾

Fuel	Fuels (10 ¹⁵ Btu)		Capacity (GWe)	
	1973 Actual	1985	1973 Actual	1985
Coal	8.6	16.2	165	324
Oil ⁽²⁾	3.6	5.9	87	129
Gas	4.5	2.6	86	49
Nuclear	1.3	12.5	21	204
Geothermal and hydro	3.1	4.8	67	193
Total	21.1	42.0	426	899

Notes: (1) Source: FEA, DEIS, March 1975 (most values)

(2) Includes gas turbines

Table 1-3

1985 FUEL MIX IN PHYSICAL UNITS⁽¹⁾

Fuel	Unit
Coal	
Western	210 MM Tons
Other	900 MM Tons
Oil	
Onshore	4.3 MMBPD
Offshore	3.6 MMBPD
Alaska	5.2 MMBPD
Synthetics	0.3 MMBPD
Imports	4.7 MMBPD
Stockpile	1 billion barrels
Gas	
Onshore	6.5 TCF/Y
Offshore	5.2 TCF/Y
Alaska	7.8 TCF/Y
Synthetics	0
Imports	0
Stockpile	0

Note: (1) Source: FEA, DEIS, March 1975 (most values)

Specific features of interest include:

- Coal supply continues to be derived from traditional Eastern and Midwestern sources; Western coal contributes only 19 percent of the total tonnage in 1985.
- Production of both oil and gas shifts dramatically from onshore to offshore and Alaskan sources by 1985. Two million barrels per day of the Alaskan oil is expected to be derived from Naval Petroleum Reserve No. 4, along with another 3.2 MMBPD from other Alaskan sources.
- The DEIS Report calls for synthetic oil production of only 0.3 MMBPD (shale oil) in 1985, despite President Ford's announced target of 1 MMBPD. The use of the lower target was explained as representative of the minimum likely impact of the President's program on import levels and, therefore, the worst case imports situation.
- A rather large crude oil strategic storage system containing 1 billion barrels of crude oil for civilian use is called for.
- The President's program specifies an import level of 4.7 MMBPD of crude oil in 1985. Strategic storage and standby authorities are expected to compensate for the imports in the event of an embargo.

Summary of Results and Analysis

The national version of the model was applied to the President's energy program to determine required energy supply and transportation facility schedules and associated resource requirements at the national level. Following that, the regional version of the model was applied to the fuel mix. Regional facility schedules were developed from this model application.

These schedules form the basis for derived schedules of direct capital, manpower, and materials for the construction and operation of energy-related facilities summarized below. All requirements are expressed without regard to the availability of such resources (additional

ie no supply constraints

availability studies would be needed in combination with these estimates of resource requirements to establish feasibility). All capital costs are expressed in constant third-quarter-1974 dollars, unmodified by escalation factors. No owner's costs (interest during construction, lease costs, etc.) are included.

Capital

The annual schedule of direct capital costs required for the construction of all energy supply and transportation facilities is indicated in Figure 1-1. Ten-year (1976 to 1985) cumulative requirements amount to \$559 billion, with annual costs increasing from \$33.6 billion in 1974 to a peak of \$62.4 billion in 1983. These costs are disaggregated by facility grouping and by energy sector in Table 1-4 and Figure 1-2. Ten-year cumulative capital costs by energy sector are:

- Electric utilities (including generation, transmission, and distribution): \$411 billion
- Oil: \$81 billion
- Gas: \$33 billion
- Coal and synthetic fuels: \$21 billion
- Nuclear fuel cycle (excluding power plants): \$14 billion

Figure 1-1. Annual Schedule of Direct Capital Requirements of the Energy Industry *

Table 1-4

**TEN-YEAR (1976-1985) CUMULATIVE CAPITAL
REQUIREMENTS OF THE ENERGY INDUSTRY,
BY FACILITY GROUPING⁽¹⁾**

Facility	Capital (\$ Billions)
OIL	
Exploration, development, and production	32.0
Refining and processing	22.7
Pipelines	8.9
Tankers, barges, trucks	6.1
Bulk stations	1.0
Other	<u>4.2</u>
Total oil	74.9
OIL SHALE	5.8
GAS	
Exploration, development, and production	19.5
Pipelines	4.2
LNG tankers	2.8
Distribution	2.9
Other	<u>3.3</u>
Total gas	32.7
COAL	
Mining	9.4
Transportation	<u>9.0</u>
Total coal	18.4
COAL SYNTHETICS	2.2
NUCLEAR FUEL CYCLE	14.0
SOLAR	0.0
ELECTRIC UTILITIES	
Coal-fired	47.8
Nuclear	116.1
Hydro and pumped storage	24.6
Oil and gas	6.1
Geothermal	<u>0.0</u>
Total Generation	194.6
Transmission	51.1
Distribution	151.8
Sulfur-removal facilities	<u>13.8</u>
Total utilities	411.3
TOTAL CAPITAL COSTS	559.3

Note: ⁽¹⁾ All costs are as constructed in 3rd-quarter-1974
fixed dollars (owner's costs excluded)

Figure 1-2. Ten-Year (1976-1985) Cumulative Capital Requirements of the Energy Industry, by Energy Sector

Manpower

Manpower results showing direct requirements for engineers, craftsmen, and teamsters and laborers for the design, construction, and startup of energy supply and transportation facilities are summarized below:

- The number of engineers required increases from 51,000 in 1974 to a peak annual requirement of 98,000 with an average annual requirement for the 1976 to 1985 period of 87,000 engineers
- The number of craftsmen required increases from 215,000 in 1974 to a peak annual requirement of 424,000, with an average annual requirement for the 1976 to 1985 period of 341,000 craftsmen
- The number of teamsters and laborers required increases from 66,000 in 1974 to a peak annual requirement of 142,000 with an average annual requirement for the 1976 to 1985 period of 127,000 teamsters and laborers

Regional Impacts

Figure 1-3 summarizes the regional results of this model application in terms of ten-year (1976 to 1985) cumulative capital investments in

each of the 14 model regions. Construction activity in the various model regions can be summarized as follows:

- Greater than \$5 billion per year: Mid-Atlantic, South Atlantic, East North Central, East South Central, West South Central Regions
- \$2.5 to \$5 billion per year: West North Central, Northern Pacific, Southern Pacific Regions
- Less than \$2.5 billion per year: Northeast, Northern Mountain, Southern Mountain, and the three coastal (offshore) regions

STUDY CHRONOLOGY

The study commenced in December 1973 and was conducted in two phases. The first phase concentrated on developing and demonstrating the methodology and computational tools and on identifying significant categories of resources in an analysis of feasibility. Phase I was concluded in August 1974, and a final report of this phase was submitted to the National Science Foundation.

The present, second, phase of the study aims at:

- Extending the time-period-of-interest for new technologies to 1995
- A regional disaggregation of the model
- A substantial development of categories of resource data for the construction and operation of energy supply and energy transportation facilities

This report describes the work as a whole; no distinction is made between the two phases of the study. The report describes the purpose for which the model was constructed, the specific purpose and scope of the data base, and the methodology used; in addition, the use of the model is illustrated by applying it to the analysis of a current energy program proposal and several alternative energy scenarios.

This report is contained in two volumes. Volume I: Model Structure and Use documents the study by describing the structure and function of the model and by illustrating its use. Volume II: User's Manual and Appendices contains complete instructions for actual execution of the computer model as well as more detailed information than contained in Volume I, including computer printouts of model runs. In addition, listings of computer programs and all data in the Energy Supply Planning Model are contained in a magnetic tape as described in the user's manual.

* ALL COSTS ARE AS CONSTRUCTED IN 3rd-QUARTER-1974 FIXED DOLLARS (OWNER'S COSTS EXCLUDED). INCLUDES COSTS FOR ENERGY SUPPLY AND TRANSPORTATION FACILITIES.

Figure 1-3. Ten-Year (1976-1985) Cumulative Capital Requirements of the Energy Industry, by Region

Section 2

MODEL OVERVIEW

This section presents an overview of the methodology and data base for the Energy Supply Planning Model, hereafter called the model. Included are discussions of the function of the model and the methodology used, system boundaries, the energy supply system, information flow in the model, and, finally, user interface considerations.

FUNCTION AND METHOD

The function of the model is to provide both the computational tools and the data base necessary to calculate the total direct capital, manpower, and material resources required to bring on-line and to operate the energy supply and transportation facilities required for any specified future energy mix in the 1975 to 1995 time frame. The approach has been to develop a large-scale computerized model of the U.S. energy supply system that can be used as a systematic planning tool to test the impact on direct resource requirements of a variety of future fuel mixes. The intent is to provide information to determine potential bottlenecks in energy supply development programs.

The method emphasizes developing a model that, while dimensionally quite large, is structurally straightforward, proceeding from user-specified assumptions for major variables, and transparent assumptions for other variables, through a series of easily understood submodels to produce resource requirements results. This decomposition into submodels is designed to allow model users a step-by-step specification of decision variables, and in so doing to permit testing the sensitivity of results to these variables.

User access to major decision points within each submodel is deliberately emphasized so that the model results represent information derived from simulation of user decisions rather than a decision-making capability provided by the model. Additionally, flexible exercise of the various user options is easily accommodated. For most user options, there is a capability to specify user considerations at various levels of detail, making the model suitable for use by energy policy-makers and analysts alike. To allow this flexibility, reference (or default) specifications exist in the model and become operative only when the user chooses not to exercise his prerogative to specify decision variables at all levels of detail.

THE U.S. ENERGY SUPPLY SYSTEM 1975 TO 1995

Central to the derivation of resource requirements for any future energy mix is a complete specification of the energy supply system that will provide that energy. Figure 2-1 specifies the interactions between the energy supply facilities needed to recover (left-hand side), process, and convert energy resources into forms ready for final consumption (right-hand side). The facilities are linked together by flows of energy; each energy flow path begins with a resource recovery facility (e.g., underground Eastern coal mine) or a port facility (in the case of imports). After recovery, a fuel may be processed (oil refining), converted to other fuels (coal liquefaction, oil gasification), converted to electricity, or used directly (natural gas).

Energy supply technologies are included in the system based on whether or not they are considered likely to make a significant impact on total system-wide resource requirements during the time period of 1975 through 1985. To meet this criterion, a technology must have a

Figure 2-1. The U.S. Energy Supply System 1970-1995

significant number of facilities operating by 1995. * Subjective application of this criterion led to the inclusion of the 66 energy supply facilities shown in Figure 2-1 and listed in Table 2-1, and to the exclusion of those technologies listed in Table 2-2.

In addition to the treatment of energy supply facilities described above, the model accounts for energy transportation, transmission, and distribution facilities requirements. Each energy flow shown in Figure 2-1 requires some means of transportation to another facility or to final demands. Table 2-3 lists the 25 energy transportation facilities included in the energy transportation system.

These 66 energy supply facilities and 25 energy transportation facilities are the essential building blocks around which the computational tools and the facilities data base are developed. The real strength of the model lies in the resulting capability to integrate system-wide requirements for any resource category over a wide spectrum of technologies and industries, so that the impact of changes in energy supply patterns can be readily determined.

The concept of a "nominal" facility is the device used to translate the 91 energy-related facilities into building blocks with certain energy technology and resource requirements (capital, manpower, and materials) characteristics. A nominal facility represents an average facility in that its resource requirements are typical of requirements for facilities of that kind likely to be under construction in the 1975 to 1985 time period. This definition implies that a nominal facility may not be identical to any existing or planned facility but will yield sufficiently accurate construction

* With a maximum 10-year engineering and construction lead time, facilities will have to be in operation by 1995 if engineering construction is initiated by 1985.

Table 2-1

ENERGY SUPPLY FACILITIES INCLUDED IN THE
ENERGY SUPPLY SYSTEM

PETROLEUM

Exploration, Development, and Production

Onshore oil production - lower 48
Offshore oil production - lower 48
Alaskan oil production

Refining and Processing

High-gasoline refinery
Low-gasoline refinery
Heavy fuel oil gasification
Naphtha gasification
Crude oil stockpile

Other

Alaskan oil export facility
Offshore crude oil import facilities
Onshore oil import facilities

OIL SHALE

Development and Production

Oil shale mine
In-situ shale oil recovery

Refining and Processing

Oil shale retorting and upgrading
Shale oil upgrading

NATURAL GAS

Exploration, Development, and Production

Onshore gas production - lower 48
Offshore gas production - lower 48
Alaskan gas production facilities
Coal mine degasification facilities

Other

Alaskan LNG export facilities
LNG import facilities
Natural gas stockpile

Table 2-1 (Continued)

COAL

Development and Production

Underground Eastern coal mine
Surface Eastern coal mine
Surface Western coal mine
Underground Western coal mine

Refining and Processing

Coal gasification (high Btu)
Coal gasification (low and medium Btu)
Coal gasification (methanol)
Coal liquefaction (heavy fuel oil)
Coal solvent refining (SRC)
Coal liquids refinery

NUCLEAR

Exploration, Development, and Production

Surface uranium mine
Underground uranium mine

Refining and Processing

Uranium mill
Uranium conversion
Uranium enrichment - diffusion
LWR fuel fabrication - no plutonium recycle
LWR fuel fabrication - plutonium recycle
HTGR fuel fabrication
FBR fuel fabrication
LWR spent fuel reprocessing
HTGR spent fuel reprocessing
FBR spent fuel reprocessing
High-level waste disposal

ELECTRIC POWER-RELATED FACILITIES

Recovery and Processing

Solid waste collection/separation plant

Electric Generation

Oil-fired power plant
Reconversion of oil-fired plant to high-Btu coal
Coal-fired power plant (low-Btu)
Coal-fired power plant (high-Btu)

Table 2-1 (Continued)

Coal/solid-waste-fired power plant (low-Btu coal)
Coal/solid-waste-fired power plant (high-Btu coal)
Sulfur oxide removal facilities
Low/intermediate Btu gas-fired plant
High Btu gas-fired power plant
Combined cycle power plant
Gas turbine power plant
Fuel cells
Light water reactor (LWR)
High temperature gas reactor (HTGR)
Fast breeder reactor (LMFBR)
Dam and hydroelectric power plant
Pumped storage
Geothermal power complex

OTHER FACILITIES

Solar space heating
Solar space conditioning

TOTAL = 66 facilities

Table 2-2

ENERGY SUPPLY FACILITIES EXCLUDED FROM THE
ENERGY SUPPLY SYSTEM

Fusion reactors
Advanced topping cycles (includes MHD)
Bottoming cycles
Solar-electric conversion technologies, including indirect sources,
wind power, tidal power, and ocean thermal gradients
Advanced battery systems
Flywheels
Compressed air storage
Hydrogen as an energy carrier
Thermionic converters
Thermoelectric generators

Table 2-2 (Continued)

Conversion of bio-mass to synthetic fuels
 In-situ conversion of coal
 Superconducting power transmission facilities
 Thorium mines
 Gas-cooled fast breeder reactor
 Domestic tar sand
 Power plant waste heat use systems
 Local energy use facilities, including nuclear and fossil industrial process heat, industrial power plants, residential furnaces, etc.

Table 2-3

ENERGY TRANSPORTATION SYSTEM FACILITIES

PETROLEUM

Transportation

Crude oil pipeline -- lower 48
 Alaskan oil pipeline
 Products pipeline
 Hot oil pipeline
 Oil tanker
 Oil barge
 Oil tank truck

Distribution

Refined products bulk station

NATURAL GAS

Transportation

Gas pipeline -- lower 48
 Alaskan gas pipeline
 LNG tanker

Distribution

Gas distribution facilities

COAL

Rail line

Coal train
 Coal barge
 Coal truck
 Coal slurry pipeline
 Coal slurry preparation
 Coal slurry dewatering

ELECTRIC POWER-RELATED FACILITIES

Transmission

Overhead transmission lines

230 kV AC
 345 kV AC
 500 kV AC
 765 kV AC
 400 kV DC

Distribution

Electricity distribution facilities

TOTAL = 25 facilities

resource requirements over the time period. The definition of a nominal facility is static; hence each definition embodies a fixed size and technology.* Individual descriptions of the nominal facilities are included in Section 6.

SYSTEM BOUNDARIES

It is important to define the system boundaries for any analysis before undertaking the effort, and it is impossible for the observer to interpret the results of any analysis without a clear understanding of these system boundaries. In the model, system boundaries of two kinds are most significant: the energy supply system boundary and the resource requirements accounting system boundary.

Figure 2-2 indicates the boundaries for the energy supply system (the reader may also refer to Figure 2-1). As shown, accounting of supply activities begins with the initiation of private company involvement in the exploration process. Preliminary survey work done by government agencies is excluded. Included in the scope of the analysis are resource recovery, processing, conversion, transportation, and local distribution activities. On the other end of the supply system, distribution to the consumer meter is included for natural gas and electricity. However, distribution activities for oil are carried only to the local product bulk station (particularly, service stations are excluded). Also, all activities associated with using "final" fuels are excluded; this includes onsite industrial boilers or power plants, residential furnaces, air conditioners, home appliances, etc.

For each nominal energy facility (both energy supply and energy transport) included in the model, certain categories of capital, manpower, and material resource requirements have been developed. This is referred to as the data base. While a complete description of the accounting system used and the categories of resource requirements employed will be

* See Appendix A for an analysis of the distortion in resource requirements results to be expected from ignoring economies-of-scale effects.

given in Section 6 of this report, a few general statements describing the boundaries of items included are warranted.

Resource requirements have been developed both for the engineering and construction of facilities and for their operation during their lifetime.

Briefly, resource requirements data are gathered for the direct costs of construction of a facility (exclusive of owner's costs such as for site acquisition and interest during construction), as well as for the direct costs of operating and maintaining each facility. All costs are expressed in third-quarter-1974 constant dollars and are given in two-digit Bureau of Economic Analysis categories (e.g. primary iron and steel products, BEA 37). Indirect costs are excluded; for example, the data base includes the purchase cost and installation requirements for a boiler in a power plant but not the (indirect) costs associated with the manufacture of the boiler. R&D costs associated with the development of new technologies are also excluded.

To complement the categories of capital costs described above, a list of selected major materials and equipment has been developed. This list contains selected major items deemed essential to the construction of energy facilities (structural steel, turbogenerators, etc.), and is significant in identifying possible constraints stemming from shortages in basic material supplies or in production capacity for major equipment.

In addition to various cost categories, resource requirements for the major engineering disciplines, designers and draftsmen, supervisors and managers; and those of major skilled craftsmen (pipefitters, electricians, etc.) as well as teamsters and laborers have been included.

INFORMATION FLOW IN THE MODEL

The Energy Supply Planning Model converts future energy mixes to facilities and attendant resource requirements schedules. A simplified overview of the methodology for accomplishing this objective is indicated in Figure 2-3, and a summary of the highlights of the information flow through the model follows.* For more detail, the reader is referred to Sections 3, 4, and 5.

Fuel Mix Generator

The user chooses a candidate future energy mix of interest, typically for the years 1975 or 1977, 1980, 1985, and 1990; or he may specify the mix for only one future year, leaving the time dependence to extrapolation schemes internal to the model. He may also specify the future mix at various levels of fuel detail, depending upon his interests (e.g. total demand for crude oil products vs fraction of crude oil supplied by oil shale vs fraction of oil shale produced by in-situ recovery facilities). In this case, missing input variables are supplied by reference (or default) variables that have been generated by the study team. The Fuel Mix Generator then converts the user or reference input variables to a complete specification of 251 annual energy flows for the years 1973 to 1995. Essentially, each flow line on Figure 2-1 is quantified annually in this manner.

National and Regional Energy Facilities Generators

The Energy Facilities Generators calculate, based on the annual energy flows from the Fuel Mix Generator, the annual schedules of energy supply facilities of various types needed on-line, both in the nation and in each region, to supply the proposed fuel mix. New facilities are defined

* Appendix B presents a retrospective analysis of the process by which the methodology was developed.

EXPLORATION, DEVELOPMENT		RECOVERY, CONVERSION, PROCESSING, PRODUCTION	TRANSPORTATION	LOCAL DISTRIBUTION	USE
GOV'T	PRIVATE				
EX- CLUDED	INCLUDED IN MODEL				EXCLUDED

Figure 2-2. Energy Supply System Boundary

Figure 2-3. The Energy Supply Planning Model: Methodology Overview, Inputs and Outputs

as ones additional to those existing January 1, 1974. The calculations of national schedules for the 66 energy facilities take into account:

- Existing facilities
- Retirements
- Planned capacity
- Nominal facility descriptions (size, conversion efficiency, etc.)

Once the schedules of new additions are determined at the national level, and at user option, these requirements are regionalized into a 14-region geographic breakdown of the United States as illustrated in Figure 2-4. The 14 regions include 11 onshore and 3 offshore regions. All onshore region boundaries coincide with state boundaries and are similar to U.S. Census Bureau regions; the seven easternmost regions are identical to Census regions.

The regional schedule of energy supply facilities is computed by applying user (or default) energy facility location coefficients to the previously calculated national facility schedules. The energy facility location coefficients specify the fraction of additional facilities of the various types that are to be located in each of the 14 regions as a function of time. (For example, locate new offshore oil production facilities entirely in the Gulf Coastal region for the 1974 to 1979 period and, thereafter, 25 percent in the Atlantic Coastal region, 25 percent in the Gulf Coastal region, and 50 percent in the Pacific Coastal region.) The output of the Energy Facilities Generator is a schedule of required facilities for each of 66 types in each of 14 regions for the years 1974 to 1995.

Interregional Fuel Allocation and Transportation Facilities Generator

The Fuel Allocation and Transportation Facilities Generator, based on the distribution of energy supply facilities over the 14 regions of the United States, allocates fuels derived from the facilities to the demand

1. NORTHEAST	8. NORTHERN MOUNTAIN
2. MID-ATLANTIC	9. SOUTHERN MOUNTAIN
3. SOUTH ATLANTIC	10. NORTHERN PACIFIC (INCL. ALASKA)
4. EAST NORTH CENTRAL	11. SOUTHERN PACIFIC (INCL. HAWAII)
5. EAST SOUTH CENTRAL	12. ATLANTIC COASTAL
6. WEST NORTH CENTRAL	13. GULF COASTAL
7. WEST SOUTH CENTRAL	14. PACIFIC COASTAL

Figure 2-4. Model Regions

of the 11 onshore regions, and calculates energy transportation facility requirements necessary to effect this distribution. The calculation takes into account user (or default) values for:

- Regional demand coefficients
- Interregional fuel flow rules
- Interregional transportation modal split coefficients

The inputs for regional demand coefficients simply specify the fraction of national final fuel demands that accrue to each of the 11 onshore regions, e.g., 0.125 of demand for motor gasoline in Northeast region, 0.086 in Mid-Atlantic region, etc.

The inputs for fuel flow rules specify a set of priority supply regions for each demand region, by fuel type. Intraregional supplies are used first; next, user preferred supply regions outside of the demand region are searched, then less favorable regions, and, finally, fuel from any supply region is accepted. For example, a typical user (or default) input might instruct the model to look first to regions 2, 3, and 5 for supplying unsatisfied coal demand in region 4, then to regions 6, 8, and 9, and finally to any region with excess supply.

The inputs for transportation modal split coefficients specify the fraction of a given flow of fuel that is to be transported from one region to another by each candidate mode. These fractions are applied to growth in fuel flows rather than to total flows; e.g., for new flows of crude oil from the Gulf Coastal region to the Mid-Atlantic region, send 1/2 of new flows by crude oil pipeline, 1/4 by oil tank truck, and 1/4 by oil tanker.

The output of the Interregional Fuel Allocation and Transportation Facilities Generator is a schedule of required energy transportation facilities for each of 25 types over each interregional link (as well as apportioned to the regions) for the years 1974 to 1990.

National/Regional Resource Requirements Generators

The Resource Requirements Generators specify, based on the annual schedule of facilities required to be on-line and on the facility resources data base existing for each facility, the annual requirements of capital, manpower, materials, and equipment for:

- Energy supply or transportation facilities
- Construction or the normal operation and maintenance of facilities
- Each facility or the whole energy system
- Each region or the whole country

Major inputs to the Resource Requirements Generators are the facility schedules described previously and facility resources data (discussed extensively in Section 6). If only national resource results are of interest, the regional calculations in Figure 2-3 may be bypassed.

Outputs from the Resource Requirements Generators comprise annual resource requirements for the years 1974 to 1985 for:

- Up to 115 construction resource categories*
- Up to 115 operations resource categories*
- 66 energy supply facilities
- 25 energy transportation facilities
- 14 regions

USER INTERFACE CONSIDERATIONS

The dimensions of the outputs of each of the four major submodels shown in Figure 2-3 are summarized in Figure 2-5. Not all of this information need be produced by a single run. The model is designed with a view

* Current model data base includes data for 77 construction resource categories and 55 operations resource categories.

toward providing users with a high degree of flexibility in the types of information produced by a given run and in the level of detail necessary for specifying input variables. This design is motivated by the belief that few users will find it significant to specify input variables at a level of detail necessary to control all the outputs. The following paragraphs summarize the major user input and output options available.

Selection of Resource Requirement Outputs

One type of user option pertains to selection of resource requirement outputs of interest. The user may specify that he wishes resource results only for:

- Certain facility types
- Certain resource category groupings

For facility type selection, the user may specify exactly which combination of the 66 individual supply facilities and the 25 individual transportation facilities are to be included in the calculation of resource requirements. Additionally, he may specify whether the results are to be printed out by facility or merely as the summation over all facilities.

For resource category groupings, the user may select any combination of the following construction requirement groupings for output:*

- Manpower (man-years)
- Capital, materials, and equipment (dollars)
- Selected major materials and equipment (physical units)

* Each group of resource categories contains several individual categories (see Section 6).

In addition, he may select any combination of the following operations requirement groupings:

- Manpower (man-years)
- Materials, equipment, and utilities (dollars)
- Natural resources consumption (physical units)

Selection of Regional Outputs

The second type of user option pertains to specifying the degree of regional analysis to be carried out. Three basic options are presented in Figure 2-6 and summarized below:

- National analysis of all facilities
- Regional analysis of energy supply facilities
- Regional analysis of energy supply and transportation facilities

The associated user input variables necessary for implementing the three regional facility analysis options are indicated in Table 2-4.

Table 2-4

INPUT AND OUTPUT STRUCTURE FOR REGIONAL FACILITY OUTPUT OPTIONS

User Specified Input Variables	Output Options		
	National Facilities	Regional Energy Supply Facilities	Regional Energy Supply and Transportation Facilities
Future fuel mix	X	X	X
Energy facility location coefficients		X	X
Regional demand coefficients			X
Interregional fuel flow rules			X
Interregional transportation modal split coefficients			X

● FUEL MIX:	251 FUEL FLOWS 23 YEARS, ANNUALLY 1973-1995
● ENERGY FACILITIES SCHEDULE:	66 FACILITIES 14 REGIONS 22 YEARS, ANNUALLY 1974-1995
● TRANSPORTATION FACILITIES SCHEDULE:	25 FACILITIES 165 INTERREGIONAL LINKS 17 YEARS, ANNUALLY 1974-1990
● RESOURCE REQUIREMENTS SCHEDULES:	115 CONSTRUCTION RESOURCE CATEGORIES 115 OPERATION RESOURCE CATEGORIES 91 FACILITIES 14 REGIONS 12 YEARS, ANNUALLY 1974-1985

Figure 2-5. Basic Model Dimensions

Figure 2-6. Regional Output Options

As can be seen, a national analysis of all facilities requires only that the user specify the future fuel mix. For a regional analysis of energy supply facilities, user (or default) input variables for the energy facility location coefficients must be specified as well. For a regional analysis of energy supply and transportation facilities, all user (or default) input variables must be specified. For the user interested in the minimum specification of input variables and the maximum amount of regional analysis, internal default values for most of the fuel mix variables and for all of the regional input variables may be employed. However, in this case the resulting outputs will simulate user interests correspondingly less well. A more accurate reflection of user interests can be gained by specifying at least the most significant input variables. A detailed discussion of user access to decision variables of various levels of significance and model default values is presented in Section 5.

Section 3

METHODOLOGY - NATIONAL MODEL

The previous section presented an overview of the Energy Supply Planning Model. This section describes in considerable detail the calculations necessary for execution of a national run of the model. It describes a national run sequence and discusses the methodological bases for the Fuel Mix Generator, National Energy Facilities Generator, National Transportation Facilities Generator, Construction Resource Requirements Generators, and Operations Resource Requirements Generators.

NATIONAL MODEL DESCRIPTION

The National Model refers to that feature of the Energy Supply Planning Model which allows the exploration of energy supply options aggregated at a national level. As compared to the regional model, the national model is more flexible, easier to apply, and is less accurate in the calculation of transportation system requirements.

For the user interested only in a national analysis, the sequence of operations illustrated in Figure 3-1 will convert a future energy mix into a schedule of energy supply and transportation facilities necessary to supply that energy mix and will calculate the set of direct resources required to bring on-line and to operate the facilities, at the national level. The method proceeds as follows:

- The user chooses a candidate future energy mix of interest, typically for the years 1975 or 1977, 1980, 1985, and 1990.

Figure 3-1. The National Model: Methodology Overview, Input and Outputs

- The computer program then calculates, by year, the number of new energy supply and transportation facilities of various types that must be brought on-stream and operated to provide that specified mix. These facilities are additional to those extant on January 1, 1974.
- The program next calculates separately the annual requirements of capital, manpower, and material required for each energy supply and transportation facility from initial commitment to plant startup through operation during its economic life. These requirements are expressed without regard to the availability of such resources.
- The program then tabulates an annual schedule of required energy supply and transportation facilities to be brought on-line and attendant annual schedules of total capital, manpower, and material requirements for the energy system as a whole.

The national model is distinctly different from the regional model in the following specific ways.

- Facility and resource requirement schedules are not regionalized.
- Energy transportation facility requirements are derived directly from fuel mix information rather than from energy supply facility requirements. This treatment is intended to provide only a very coarse approximation to transportation requirements. For the user with real interest in the implications of future energy programs on the energy transportation system, or resource requirements derived therefrom, the regional analysis capability of the model, summarized previously in Section 2 and discussed in detail in Section 4, is recommended.

The following sections detail the methodology developed for each sub-model associated with the national run sequence of Figure 3-1. Systems programming aspects of the sequence are discussed in Volume II.

FUEL MIX GENERATOR

Function

The function of the Fuel Mix Generator is to convert flexible user inputs into a complete specification of all annual energy flows during the 1973 to 1995 time period. The primary purpose is to develop this future energy mix into a form suitable for the subsequent calculation of national energy supply facility requirements. A secondary objective is the specification of flows suitable for a coarse, nationally aggregated calculation of energy transportation facility requirements.

The input to the Fuel Mix Generator is the most significant user interface to the Energy Supply Planning Model. Because of this fact, the input structure is designed to provide a high degree of user flexibility in specifying fuel mix considerations at various levels of detail so that the model can be accessed by energy policy-makers and analysts alike. For users who choose to specify inputs at a high level of aggregation, missing input variables are supplied by reference (default) values generated by the study team. The user inputs are transformed into fuel mix outputs according to the rules specified by the calculational algorithms of the Fuel Mix Generator. This section describes the methodology for generating these outputs. The user input interface is described in Section 5.

Method

The steps employed in the Fuel Mix Generator to develop the output matrix from the given input matrix are shown in flow graph form in Figure 3-2 and are summarized as follows:

- Using the input variables specified by the user and default values for the remaining variables, annual fuel requirements are generated for the time period 1973 to 1995. This step is accomplished by the Growth Model GM 1. The choice of interpolation scheme depends upon whether one or more future estimates are provided.

Figure 3-2. Flow Graph of the Fuel Mix Generator

- Using the given input structure, the annual capacities of various sources that can supply the fuel requirements from 1973 to 1995 are determined. This step is accomplished by Growth Model GM 2.
- Steps A and B are combined through a source allocation scheme to determine the contribution of applicable sources in meeting the relevant fuel requirements. This step is accomplished by Submodel 2.

The Fuel Mix Generator is computerized using the algorithms described above.

Input and Output Structures

The input and output structures of the Fuel Mix Generator are summarized in Figure 3-3.

Figure 3-3. Input and Output Structure of the Fuel Mix Generator

The major output of the Fuel Mix Generator is a (251 x 23) matrix that is used in subsequent calculations of energy supply facility requirements, with eighteen additional outputs (for each of 23 years) for use in calculating the transportation facility requirements. The output matrix is generated from user-specified inputs. The 117 total such input variables together specify a supply and demand fuel mix for any year.

The input is structured to express the fuel mix of interest in a form usable by the model and that allows the user flexibility to enter inputs at various levels of detail. The 117 input variables are divided into three sets of variables:

- Overview variables
- Primary variables
- Secondary variables

The three sets of variables differ mainly in their informational requirements. Most overview variables and primary variables represent fuel demand (e. g. motor gasoline) and policy variables (e. g., amount of oil to be stored in 1985) while most secondary variables specify the capacities of supply sources to satisfy the demand. Thus, usually more detailed, technical information is required to specify a secondary variable than a primary variable or an overview variable. For instance, more detailed technical information is necessary to specify the percentage of nuclear reactors that will recycle plutonium in 1980 (a secondary variable) than to specify motor gasoline demand in 1980 (an overview).

These variables are supplied for 1 to 5 future years, typically for the years 1977, 1980, 1985, and 1990.

Computational Logic

The modeling scheme is shown in Figure 3-4; two models specify the rules for transforming the user-specified input matrix into the output matrices:

- Submodel 1 develops a growth curve from 1973 to 1995 for each of the 24 overview variables, 20 primary variables, and 73 secondary variables. The growth curve is constructed from the information contained in the input matrix. Submodel 1, in turn, consists of two Growth Models, one for fuel requirements and another for sources of fuel supply.
- Submodel 2 allocates a particular fuel requirement (e.g. motor gasoline) to the relevant supply sources (e.g. shale oil, onshore crude, etc.). These estimates are derived by developing a source allocation scheme.

These two submodels will be discussed in the following paragraphs.

Submodel 1: Growth Models

As indicated in Figure 3-4, there are two growth models:

- Growth Model GM 1 estimates annual fuel requirements from 1973 to 1995; for example, motor gasoline demand in million barrels per day.
- Growth Model GM 2 estimates annual capacities of sources of supply; for example, the fraction of coal requirements derived from Eastern underground coal mines.

Essentially, the two growth models interpolate the input variables for either 1973 to 1985 or 1973 to 1990 time periods and then extrapolate for either 1985 to 1995 or 1990 to 1995 periods.

Figure 3-4. Modeling Scheme for Fuel Mix Generator

Growth Model GM 1. This model deals with fuel requirements. All of the 24 overview variables, 20 primary variables, and only 8 of the secondary variables are interpolated and extrapolated by this model.

For interpolation purposes, it must be specified how the growth takes place during the 1973 to 1985 or 1973 to 1990 time periods. Such specification establishes the rules for interpolation purposes. For extrapolation purposes, the model assumes continued growth at the 1980 to 1985 or the 1985 to 1990 rate depending upon the number of future estimates supplied by the user.

Theoretically, future growth can follow a large number of growth curves. However, on practical grounds, two growth curves have been popularly employed: exponential and linear. Exponential growth of a variable implies that the growth rate varies linearly over time. Linear growth, on the other hand, implies that a variable itself grows linearly over time. Therefore, a choice must be made concerning how future growth is assumed to take place.

A choice between the two assumptions becomes reasonably simple if the user provides at least four future estimates of a variable; that is, when the input matrix is at least (117×4) . In this case, the four future estimates implicitly contain the user's perception of the future. However, when only a single estimate for the future is provided, a choice must be made between exponential and linear growth assumptions. In the present model, an exponential growth is assumed between the present value of a variable and the estimate provided by the future value.

When the input matrix comprises more than one future estimate, the interpolation scheme consists of fitting an appropriate number of linear segments for the time periods corresponding to the future years.

For instance, if 1977, 1980, 1985, and 1990 estimates are provided, four linear segments are fitted between 1973 to 1997, 1977 to 1980, 1980 to 1985, and 1985 to 1990. The general form for each linear segment is the following:

$$Y(t) = Y(t_0) + k(t - t_0)$$

where

$Y(t)$ = value of a variable at time t

$Y(t_0)$ = initial value of the variable, i. e. at time t_0

k = growth rate during $(t - t_0)$.

Four exponentials can be fitted instead of four linear segments. The model employs linear interpolation because it yields values of a variable within one percent of that obtained if fitted with an exponential, if $(t - t_0) \leq 5$ years. In addition, the linear interpolation scheme is computationally more efficient.

When the input matrix is (117×2) , i. e. a single future estimate is provided, the interpolation scheme fits an exponential curve for the time period of interest. This exponential has the following form:

$$Y(t) = Y(t_0) \exp \left[b(t - t_0) \right]$$

where

$Y(t)$ = value of a variable at time t

$Y(t_0)$ = initial value of the variable, i. e. at time t_0

b = a constant signifying the slope of the exponential curve.

Linear interpolation, if employed in this case, would significantly overestimate the value of a variable since a minimum time span of 12 years (1973 to 1985) is involved.

Figure 3-5 shows four types of situations to be approximated by an exponential growth curve. The curves for V_1 and V_3 can be fitted by the general form mentioned above. However, complications occur when attempting to fit an exponential for V_2 and V_4 since such an exponential never attains a value equal to zero.

The complications can be overcome if the user can supply to the model estimates of the growth rate envisioned for the time period of interest. The growth rate is to be specified for only those variables having zero values for either 1973 (V_2) or 1990 (V_4). Most of these variables represent either new technologies (e.g. shale oil) or imports (e.g. crude oil). The growth curves for V_2 and V_4 can then be constructed by determining the initial and final values implied by these user-specified growth rates.

It should be noted that such complications do not occur when the user specifies four future estimates and the linear interpolation scheme is employed.

Growth Model GM-2. As mentioned previously, this model estimates annual capacities of various sources of supply using an interpolation scheme for 1973 to 1990 and an extrapolation scheme for the 1990 to 1995 time period. Sixty-five secondary variables are interpolated and extrapolated by this growth model.

The model assumes no shift in the capacity of supply sources during the time period 1973 to 1975. This seems to be a reasonable approximation considering the time lags involved in opening up new sources or in expanding the present sources of supply. Linear interpolation schemes are used to estimate variable behavior during 1975 to 1985 or 1975 to 1990 time periods. For extrapolation, user input determines

Figure 3-5. Four Possible Exponential Growth Curves

the growth rates during the 1985 to 1990 or 1990 to 1995 time periods. Depending upon the user input, the values of a secondary variable are kept constant either for the 1985 to 1995 or 1990 to 1995 time period.

Submodel 2: Source Allocation Scheme

A fuel requirement can be supplied by a number of sources. For instance, coal can be supplied from underground mines, surface mines, or can be imported. To determine energy facility requirements (e.g. the number of underground Eastern coal mines needed in 1980), one must specify the amount of fuel supplied by various sources. Submodel 2 specifies the rules for deriving a particular annual fuel requirement from the relevant sources of supply.

The general expression for such rules can be determined as follows. For a given year, let:

f_i = annual requirement for the i^{th} type of fuel
 a_{ij} = the fraction of total requirements for i^{th} type of fuel supplied by the j^{th} source

Then $S_{ij} = a_{ij} \cdot f_i$ specifies the amount of the i^{th} type of fuel derived from the j^{th} source. If there are N sources that can contribute to meeting the requirements of the i^{th} type of fuel, then the summation $\sum S_{ij}$ must equal f_i . If there are M types of fuels then the above process has to be repeated M times. The quantity S_{ij} yields the value for one of the output variables for the given year. It can be recalled that the quantities f_i and a_{ij} are determined by Growth Models GM 1 and GM 2.

An example will illustrate the above scheme. Figure 3-6 shows how a fuel requirement - natural gas for direct use - can be supplied by

Figure 3-6. Sample Logic Diagram of Source Allocation Scheme

various sources, thirteen in this case. Figure 3-6 also indicates the relevance of and relationships among overview, primary, and secondary variables. The network shown in Figure 3-6 represents the flow of natural gas from supply nodes to the demand node and may be derived from information contained in Figure 2-1.

The contribution of each of the thirteen sources to supply of natural gas demand depends on the capacities of the various sources; these capacities can be expressed as a_{ij} and b_{jk} . The subscript $i = 1$ refers to the fuel (natural gas in this case). The quantities a_{1j} , $j = 1 \dots 6$ expresses the fact that natural gas can be derived from six primary sources. The conventional sources in turn can be onshore wells, offshore wells, and Alaskan production facilities. The contribution of these three sources is expressed through the quantities b_{1k} , $k = 1 \dots 3$. Similarly, other paths in Figure 3-6 can be traced and quantified. It may be recalled that quantities f_i , a_{ij} , and b_{jk} are generated in Submodel 1.

The amount of natural gas, for a specific year, derived from a particular source on the right-hand side of Figure 3-6 can be determined by multiplying the natural gas requirements for the year by appropriate fractions. As an example, the amount of natural gas derived from onshore wells, in year 1975, can be determined as follows:

$$\begin{bmatrix} \text{Amount of} \\ \text{natural gas} \\ \text{from onshore} \\ \text{wells in 1975} \end{bmatrix} = \begin{bmatrix} \text{Natural gas} \\ \text{requirements} \\ \text{in 1975} \end{bmatrix} \times \begin{bmatrix} a_{11}(1975) \end{bmatrix} \times \begin{bmatrix} b_{11}(1975) \end{bmatrix}$$

The annual values of most output variables for the time period 1973 to 1995 are determined in a similar manner by developing the appropriate rules.

NATIONAL ENERGY FACILITIES GENERATOR

Function

The function of the National Energy Facilities Generator is to calculate, based on the annual energy flows derived from the Fuel Mix Generator, the annual schedules of energy supply facilities of various types needed on-line to satisfy the fuel mix for that year at the national level. Required schedules are determined both for new additions, that entail expenditure of construction resources, and for the total number of operating facilities, that necessitate expenditure of operations resources. These schedules are used for the subsequent calculation of resource requirements.

It is emphasized that the energy supply facility schedules are derived directly from the user-specified fuel mix. Hence, the time feasibility of that fuel mix can be investigated by analysis of the required construction schedules along the following lines:*

- Will the planning environment permit the plant construction commitments to be made when required?
- For facilities with construction lead times longer than the number of years between the present and the on-line date requirements, are an adequate number of such facilities currently in the appropriate engineering or construction stage?

Method

The method for calculating required energy supply facilities is based on tracking energy flows through the chain of facilities needed to supply

*To carry out such feasibility analysis, model results of required schedules would necessarily have to be supplemented by information about construction plans and commitments. No such information has been developed within this study. Development of such data would be a very significant contribution to the capability of conducting feasibility analysis.

those flows. The energy supply system diagram in Figure 2-1 provides the information necessary to determine which facilities are triggered by the various categories of energy in final demand. In fact, the same diagram was used to identify the energy flows necessary to totally specify facility requirements. The Fuel Mix Generator was then designed to produce these flows as output.

An energy facilities matrix is used to quantify the above mentioned relationships between energy flow and facility requirement. This matrix was developed using nominal facility descriptions (see Section 6) which define:

- Facility size
- Facility capacity factor *
- Facility conversion efficiencies

A straightforward matrix multiplication scheme produces the total number of each facility type required to satisfy the fuel mix in each year.

The number of annual additions of each facility type is then computed based on the total number of facilities required to be on-line in each year. This calculation takes into account the following information:

- Initial conditions for number of facilities existing in 1973
- Fraction of 1973 capacities retired annually
- Operating lifetimes of new facilities
- Planned additions of capacity

The schedules of facility totals and new additions calculated in this manner presume that final demands for fuels can be supplied without

* Capacity factors for power plants are a user-specified decision variable (see Table 5-1)

any delay from the time facilities are started up. This approximation is fairly good for supply chains in which there is little time lag between resource recovery and production of fuel for final consumption; this is true for most domestic supply chains. However, in the nuclear fuel cycle a period of close to two years may pass from the time ore is recovered to the time electricity can be produced using that ore. This system lead time must be accounted for to derive accurate facility schedules. Hence, the final step involves time-shifting facility schedules to correct for this effect, called in subsequent discussion the "system lead time."

Various special computations are carried out to account for facilities not amenable to treatment by the basic approach outlined above (e.g. multiple-output facilities).

Input and Output Structures

A summary of major inputs for the National Energy Facilities Generator is given in Figure 3-7. Inputs include:

- Fuel mix, 251 annual energy flows, 1973 to 1995
- Nominal facility definitions
- Facility retirement data
- Initial conditions, number of facilities of the various types existing in 1973 (calculated if not specified externally)
- Planned additions of capacity

Outputs include:

- Annual schedule of new additions of energy supply facilities (66 types) required to satisfy the fuel mix, 1974 to 1995
- Annual schedule of facility on-line totals (66 types) required, 1974 to 1995
- Byproduct supplies of secondary fuel products (jet fuels and kerosenes, other light products, all other products, byproduct electricity), 1973 to 1985

Figure 3-7. Input and Output Structures of the National Energy Facilities Generator

Computational Logic

Basic Logic. Figure 3-8 depicts the computation scheme for one cycle, a typical year t . The results from one cycle are the determination of required numbers of on-line facilities and new additions to capacity in that year t for each of the 66 nominal energy supply facilities. The major operations in each cycle are:

1. **Facilities Generator** - determines the total number of each type of energy supply facility required to supply fuel mix in year t .
2. **Adjust for Retirements** - updates current information on existing facility capacities to account for retirement of old facilities.
3. **Incremental Facility Generator** - determines number of new nominal energy supply facilities of each type which must begin operation in year t .
4. **Compare with Planned Additions** - compares required additions to capacity with additions currently planned by industry to determine greater number of additions.
5. **Update Existing Facilities** - updates current information on energy facility capacities to account for new additions to capacities.

Figure 3-8. Facilities Requirements Generator

Each operation is described in the following paragraphs.

- **Facilities Generator.** The Facilities Generator converts the reference fuel mix into facility requirements using an energy facilities matrix that takes into account facility sizes, capacity factors, and conversion efficiencies as defined by nominal facility descriptions. The energy facilities matrix is constructed so that the matrix coefficients are defined as the number of nominal facilities of the specified type required to produce a given amount (flow unit) of a specified energy flow type.

The logical basis for constructing the matrix is illustrated for two of the thirteen fuel mix outputs shown earlier in Figure 3-6 and represent the supply of natural gas from the coal gasification process, using underground Western coal and surface Western coal as the two alternative sources of coal. Figure 3-9 indicates the resulting matrix entries. The rows of the matrix are the energy flows; the columns are the nominal energy supply facilities types. "Flow unit" is the amount of each energy flow upon which the matrix coefficients (the required number of nominal energy facilities) are based. The complete energy facilities matrix is 248 energy flows by 66 energy supply facilities.

The energy facilities matrix is modified with each run of the model, based on user specification of power plant capacity factors (see Section 5).

The matrix is used to calculate required numbers of energy facilities in the following way:

Let

e_i = amount of energy flow of type i

u_i = amount of flow unit of type i

f_{ij} = matrix coefficients, number of nominal energy supply facilities of type j required to produce u_i

and

f_j = total number of nominal energy supply facilities of type j required

FUEL MIX FLOW	FLOW UNIT	FACILITY TYPE	MATRIX COEFFICIENT	FACILITY TYPE	MATRIX COEFFICIENT
ROW 42	1 TCF/YR	26	38.1	27	11.0
ROW 43	1 TCF/YR	25	19.0	27	11.0

ROW 42: 1 TCF/YR OF NATURAL GAS FROM UNDERGROUND WESTERN COAL REQUIRES

- 38.1 UNDERGROUND WESTERN COAL MINES (2 MM TONS/YR) – TYPE 26 FACILITY
- 11.0 COAL GASIFICATION-HIGH Btu (250 MM CF/D) PLANTS – TYPE 27 FACILITY

ROW 43: 1 TCF/YR OF NATURAL GAS FROM SURFACE WESTERN COAL REQUIRES

- 19.0 SURFACE WESTERN COAL MINES (6 MM TONS/YR) – TYPE 25 FACILITY
- 11.0 COAL GASIFICATION-HIGH Btu (250 MM CF/D) PLANTS – TYPE 27 FACILITY

Figure 3-9. Sample Energy Facilities Matrix Entries

Then, the total number of nominal facilities required for a specified facility type j is the sum of those required for all energy flows. In matrix notation, this is:

$$\tilde{f} = \tilde{A} \times F$$

where

$\tilde{f}$ = 66-element required facility vector whose elements are f_j

$\tilde{A}$ = 248-element vector whose elements are defined by $a = \frac{e_i}{u_i}$

$[F]$ = 248 x 66 energy facilities matrix of f_{ij}

- Adjust for Retirements. One other step must be executed before determining a schedule of facilities. The base-line capacities of existing facilities for each year must be determined; this is calculated by adjusting the existing capacities at the beginning of the

preceding year (which is calculated during the computation cycle for year $t-1$) downward to account for retirement of old facilities during the preceding year. *

Required input data for this calculation consists of:

- Fraction of existing 1973 capacities retired each year
- Lifetimes for new facilities constructed in 1974 to 1995 period

The replacement function vector is then calculated, taking into account the number of facilities existing in 1973 that must be retired and the number of facilities built since 1973 that have outlasted their lifetimes. This vector is then subtracted from the previous year's updated facility vector to obtain the current year's adjusted facility vector.

- Incremental Facilities Generator. The requirements for construction of new energy supply facilities sufficient to meet the fuel mix specifications for year t can now be determined in a straightforward manner by the Incremental Facilities Generator. The incremental facility vector is obtained by subtracting the adjusted facility vector from the required facility vector.

An integral number of new facilities is added, after rounding the above result to the next whole number if the fractional requirement exceeds a threshold value (from 0-1, typically .33), or rounding downward otherwise.

- Compare with Planned Additions. By nature of the lead times inherent in construction schedules, industry has already begun construction of many facilities that will begin operation in the next several years. While no such data have been gathered within this study, the purpose of the compare with planned additions step is to allow accounting for excess planned capacity, if such data were available. The actual number of new facilities added in year t by the incremental facility vector is, therefore, the greater of the two numbers:

* Requirements for the initial year of model operation (1973) may be calculated based on the 1973 fuel mix flows or input directly.

- Required additions to capacity
- Planned additions to capacity
- Update Existing Facilities. The current year's updated facility vector is computed by adding the incremental facility vector to the adjusted facility vector.
- Time-Shifting. Prior to using the incremental facility vector (number of new facilities) or the updated facility vector (total facilities on-line) as input to the calculation of construction and operations resource requirements, a time-shifting may be necessary for certain facilities to account for a system lead time. This accounting effectively determines the required startup dates for various facilities in a supply chain, based on the fact that sequencing facilities involves time lags from one facility to the next. For example, to supply a certain amount of electricity, a uranium mine and mill might be opened 2 years before power plant startup. Annual schedules of new additions and total on-line requirements are shifted by one year if the system lead time is greater than 6 months, 2 years if greater than 18 months, etc. For current model system lead time data, this algorithm results in actual shifting only for nuclear fuel cycle facilities.

The computation scheme cycles in the described manner through the calculations for all years of the planning horizon. Following completion of all cycles, summaries of the number of additions of each facility type for the years 1974 to 1990 are printed.

Special Cases. The basic logic described above for determining required facility schedules must be modified for certain energy supply facilities with special characteristics. There are four general classes of such special facilities:

- Facilities for which the decision to build new capacity may involve demands for more than one kind of fuel output (e. g. refineries)

- Facilities for which the decision to build new capacity is based on one fuel output, but which produce a by-product output of a secondary fuel (e.g. oil and gas production facilities)
- Facilities for which the decision to build new capacity may be based on nonquantifiable considerations to a large degree (e.g. facilities for the storage of high-level radioactive waste)
- Facilities which are converted from one type to another type (e.g. oil-to-coal power plants)

In addition, logic is required to print feasibility-related information about facility construction schedule results.

- Refinery Balancing Scheme. Because refineries manufacture several products and, once constructed, their design allows the production of only certain types of products in only certain yields, special logic is needed to determine facility requirements. In the model six types of refined products are considered:
 - Motor gasoline
 - Jet fuels and kerosenes
 - Distillate fuel oil
 - Other light products (naphtha, gas liquids, petrochemical feedstocks, etc.)
 - Heavy fuel oil
 - All other products (lubricating oil, paraffin wax, etc.)

However, only three of these are used as "decision" products whose demand stimulates the construction of new capacity: motor gasoline, distillate fuel oil, and heavy fuel oil.

The model includes three types of refineries to supply these demands:

- High-gasoline refinery
- Low-gasoline refinery
- Coal liquids refinery (feedstock is heavy fuel oil from coal liquefaction plant)

In addition, heavy fuel oil can be supplied directly by coal liquefaction facilities. All three oil products may be supplied by imports as well. Nominal facility descriptions for the three refineries indicate that the coal liquids refinery produces mostly motor gasoline and some distillate fuel oil, but no heavy fuel oil; the high-gasoline refinery produces the same mix of fuel; and the low-gasoline refinery produces all three types of fuel, principally the two fuel oils.

A refinery balancing scheme has therefore been developed that embodies the following principles:

- Facility requirements for coal liquids refineries are determined by motor gasoline demands; a byproduct of distillate fuel oil is produced
- Facility requirements for high-gasoline refineries are determined by motor gasoline demands also; a similar byproduct of distillate fuel oil is produced
- Facility requirements for low-gasoline refineries are determined by demands for distillate fuel oil (after accounting for byproducts from the above refineries) and by demands for heavy fuel oil; byproducts of motor gasoline serve to decrease the required capacities of the high-gasoline refineries
- Enough low-gasoline refineries are built to satisfy at least the unsatisfied demands both for distillate fuel oil and heavy fuel oil. If the demand for heavy fuel oil dominates, the refineries will blend high-quality distillate (low-sulfur) with the heavy fuel oil to minimize capacity requirements. If the demand for distillate fuel oil dominates, additional refineries will be built; and there will be excess heavy fuel oil capacity, since its sulfur content prevents mixing it to produce additional distillate
- Byproducts of jet fuels and kerosenes, other light products, and all other products are calculated for use in a byproduct accounting scheme described in the following paragraphs

- Byproduct Accounting. Several facilities produce quantities of secondary fuels (byproducts) which do not enter directly into the calculation of required facility capacities. An accounting of the supply and demand for these byproducts is printed following completion of the primary calculations. No effort is made to bring supplies and demands into balance. Fuels treated in this manner include the three categories of refined products considered in the Refinery Balancing Scheme and byproduct electricity produced in certain energy-related facilities (high-gasoline refinery, low-gasoline refinery, and coal gasification-low Btu).

Certain other facilities produce quantities of byproduct fuels that, while not figuring in the capacity requirements for the producing facility, do affect the capacities of other facilities whose primary product is that fuel. In these cases, byproduct credits are accounted for by reducing the required capacities of the affected facilities. Byproduct fuels accounted for in this manner include:

- Motor gasoline from low-gasoline refineries, credited to required capacity of high-gasoline refineries
 - Distillate fuel oil from high-gasoline refineries and coal liquids refineries, credited to required capacity of low-gasoline refineries
 - Natural gas from onshore oil production, offshore oil production, and Alaskan oil production facilities, credited to the required capacities of the respective gas production facilities
 - Crude oil from Alaskan gas production facilities (actually natural gas liquids assumed to be mixed in crude oil flows), credited to the required capacity of Alaskan oil production facilities
- High-Level Waste Disposal Facilities. The high-level waste disposal facility receives storage casks containing solidified high-level radioactive waste from nuclear fuel reprocessing facilities. One such facility is likely to be built within the planning horizon of the model, but the on-line date is subject to considerable speculation and not based simply on the level

of installed nuclear power capacity. Hence, this facility is treated uniquely by direct user specification of the required startup year for the facility.

- Reconversion of Oil-Fired Power Plant to Coal. One of the nominal facilities involves reconversion to coal of a power plant which was originally designed to burn coal but had switched to oil prior to 1974. Special logic is required to account for the fact that each reconversion of this type of plant is a retirement of an equivalent capacity of oil-fired power. This logic is implemented by reducing the updated facility value for oil-fired power plants by the amount of reconversions of oil-fired power plants to coal added during a given year.
- Feasibility Messages. A major output of the National Energy Facilities Generator is a printout of required schedules of new energy supply facilities of the various types. These schedules are calculated directly from the user-specified fuel mix, without regard to the feasibility of bringing the required facilities on-line in the required time. For the construction schedules to be feasible, construction activity must be well underway at the current time for facilities required on-line in the next few years. To indicate possible sources of this kind of infeasibility, asterisks are included as part of the printout when the following condition is met:

"The construction schedule for this facility is longer than the number of years between the present and the on-line date. If the facility is not currently in the appropriate engineering or construction stage, the fuel mix may not be feasible."

NATIONAL TRANSPORTATION FACILITIES GENERATOR

The function of the National Transportation Facilities Generator is to produce a gross estimate of required annual additions to energy transportation facility capacities as well as a schedule of existing facilities during the period 1974 to 1990 to transport the fuel flows specified by the Fuel Mix Generator. This information becomes the input to the National Transportation Construction and Operations Resources Generators.

Method

The methodology used assumes a single two-node system of flow from supply to demand. First, national flows of the 18 fuel types considered are allocated to the 24 possible modes via modal-split coefficients.*

Table 3-1 indicates the transportation modes available to various fuel types. Facility requirements by fuel are computed by multiplying the flow in each mode by a national average haul length for that mode and then dividing by the capacity of a nominal facility (specified in terms of MM bbl-miles/year, for example). These requirements are then summed by fuel type to yield total facility requirements.

The remainder of the logic is essentially identical to that described previously for the National Energy Facilities Generator. First, the facilities to be retired over the course of the year are calculated using a time-dependent retirement function. This number is subtracted from the number of facilities existing at the end of the preceding year. The difference between required facilities and the adjusted existing facilities is the number of required additional facilities needed to transport all fuels. The number of required additional facilities is rounded-up to an integer number of incremental facilities to be built each year.

The user has the option of specifying planned facility additions in each year. The model takes as the number of incremental facilities to be built the greater of the planned additions to capacity or the required

* In the national model, resource requirements data have been developed for 24 nominal transportation facilities, including trains. However, in the determination of train requirements, two uses of trains are considered to account for the fact that unit trains and conventional trains are likely to operate at different capacity factors. In addition, conventional trains may carry oil as well as coal.

Table 3-1

NATIONAL TRANSPORTATION FACILITIES GENERATOR
TRANSPORTATION MODES AVAILABLE TO VARIOUS FUEL TYPES

Fuel Type	Transportation Mode																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	Crude Oil Pipeline	Alaska Pipeline	Refined Prod. Pipeline	Hot Oil Pipeline	Oil Tanker	Petroleum Barge	Petroleum Truck	Bulk Oil Dist. Facility	Rail Line	Train	Slurry Pipeline	Slurry Prep. & Dewatering	Coal Barge	Coal Truck	Gas Pipeline	Alaska Gas Pipeline	LNG Tanker	Gas Dist. Facility	230 kV Trans.	345 kV Trans.	500 kV Trans.	765 kV Trans.	±400 kV DC Trans.	Elect. Dist. Facility
1. Domestic offshore crude	X				X	X	X		X	X														
2. Domestic onshore crude	X				X	X	X		X	X														
3. Imported overland crude	X				X	X	X		X	X														
4. Imported overseas crude	X				X	X	X		X	X														
5. Alaskan crude	X	X			X	X	X		X	X														
6. Domestic refined products			X		X	X	X	X	X	X														
7. Imported overland refined products			X		X	X	X	X	X	X														
8. Imported overseas refined products			X		X	X	X	X	X	X														
9. Domestic heavy fuel oil				X	X						X													
10. Imported overland heavy fuel oil				X							X													
11. Imported overseas heavy fuel oil				X	X						X													
12. Domestic offshore natural gas															X			X						
13. Domestic onshore natural gas															X			X						
14. Imported overland natural gas															X			X						
15. Imported overseas natural gas															X	X	X	X						
16. Alaskan natural gas															X	X	X	X						
17. Coal									X	X	X	X	X	X										
18. Electric Power																			X	X	X	X	X	X

additions to capacity. Adjusted existing capacity is then updated by adding these incremental facilities. The model then begins calculations for the next year.

CONSTRUCTION RESOURCE REQUIREMENTS GENERATORS

Function

The Construction Resource Requirements Generators specify the time-phased requirements of capital, manpower, and materials for the construction of each facility and of the whole energy system. The purpose is to provide integrated, system-wide construction resource requirements for any fuel mix, based on the annual schedule of new energy supply and transportation facilities. The calculations are carried out separately for energy supply and transportation facilities, but the logic is identical.

Method

The key steps in the computational procedure are:

- Time-phasing the construction resource requirements for individual facilities by resource type and by year
- Integrating individual facility results into system-wide totals by resource type and by year

Principal data required are the total resources for the construction of energy supply and transportation facilities. These resource requirements are then broken down to an annual basis by percentages expended during each year of the construction period. These data are multiplied by the number of additions of each facility type scheduled for startup in each year. System-wide integration is accomplished by simple summation of the individual facility results.

Input and Output Structures

Figure 3-10 indicates the input and output structures of the Construction Resource Requirements Generators. Major inputs are:

- Annual startup schedules 1974 to 1995 for energy supply facilities (66) or energy transportation facilities (24)
- Facility resource requirements data (up to 115 categories) for energy supply (66) or transportation facilities (24)

Outputs are annual schedules (1974 to 1985) of resource requirements for the construction of energy supply or transportation facilities, individually and for the whole energy system.

Figure 3-10. Input and Output Structures of Construction Resource Requirements Generators

Computational Logic

The calculations first determine resource requirements for individual facility types by year, taking into account that:

- When a particular energy supply facility has to come on-line at a particular time, engineering and construction of that facility must begin early enough to allow the time needed.
- When production of energy in a final form ready for consumer use (e. g. electricity) has to occur at a particular time, the on-line date for the energy supply facility must be early enough to allow for any system lead time between facility startup and production of energy in the required form

As an example, a uranium mill has a system lead time of 22 months and an engineering construction period of 16 months. Hence engineering of the mill must begin 38 months before the required production of electricity in a nuclear power plant, based on ore refined at that mill.

In the model, for the purpose of allocating construction resources to the proper calendar year, resources data are partitioned into successive 12-month periods preceding the year of final energy production. For uranium mills started up to satisfy electricity demand in 1978, no construction resources will be expended during the system lead time phase (all of 1977 and 10 months of 1976), and all construction resources will be expended during the preceding 16 months - 2 months of 1976, 12 months of 1975, 2 months of 1974. In a similar manner, uranium mills started up for electricity production in 1979 will have construction resource requirements in 1975, 1976, and 1977; and so on. Total requirements in 1976 for the construction of uranium mills can thus be obtained by summing the results for mills started up in 1978, 1979, and 1980. In general, for uranium mills started up for production of electricity in any year, construction resources will be expended for 2 months in the fourth year prior to startup, 12 months in the third year prior to startup, and 2 months in the second year prior to startup.

One additional data manipulation is required to carry out the calculations because construction resources are expended at various rates during the construction period. It is necessary to know not only the total resources of a given type expended during the construction period but also the percentage of the total resources that is required during each year (or phase) of the construction period. Different sets of percentages were developed for six different resource category groupings:

- Technical nonmanual manpower
- Nontechnical nonmanual manpower
- Craftsmen
- Laborers and teamsters
- Materials and equipment
- Total capital

The uranium mill has a total capital cost of \$7 million. During the engineering and construction period of 16 months, 80 percent of the capital cost is required in the first 12 months and 20 percent in the last 4 months. Hence, this resource is being expended at a rate of \$465,000 per month for the first 12 months (7 million x 80 percent +12 months) and \$350,000 per month for the final 4 months. For uranium mills started up for electricity production in 1978, construction resources are therefore expended at the rate of \$465,000 per month for 2 months of 1974 and 10 months of 1975, and at the rate of \$350,000 per month for 2 months of 1975 and 2 months of 1976.

For each type of facility, construction resources in the six groupings are partitioned into data in the above form: amounts expended at various rates during each of the calendar years prior to production of final energy forms.

This information can be used to generate total resource requirements in each year. For example, for each uranium mill started up in 1978, total capital cost requirements will be \$930,000 in 1974; \$5,370,000 in 1975; and \$700,000 in 1976.

In general, given the number of facilities required for startup in each year, total construction resources of a given type required in year T for a particular facility can be determined by the equation:

$$R(T) = \left[\frac{Rp_1}{m_1} \cdot M(r_1, t-1) + \frac{Rp_2}{m_2} \cdot M(r_2, t-1) + \dots \right] \cdot S(T+1) + \left[\frac{Rp_1}{m_1} \cdot M(r_1, t-2) + \frac{Rp_2}{m_2} \cdot M(r_2, t-2) + \dots \right] \cdot S(T+2) + \dots$$

where $R(T)$ = Resources required in year T of a particular type for a particular facility

R = Total resources of a particular type required for the construction of the facility

$S(T+1), S(T+2) \dots$ = The schedule (number) of facilities required to start up for the production of final energy in year T+1, T+2 ...

$M(r_1, t-1), M(r_2, t-1) \dots$ = the number of months during which total resources are expended
 $M(r_2, t-2), M(r_2, t-2)$ at rate 1 in year 1 prior to startup,
 at rate 2 in year 1 prior to startup,
 at rate 1 in year 2 prior to startup,
 at rate 2 in year 2 prior to startup,
 at rate r in year t prior to startup,
 etc.

$m_1, m_2 \dots$ = number of months in first phase of construction period, second phase of construction period...

$p_1, p_2 \dots$ = percentage of total resources expended during first phase of construction period, second phase...

The computations cycle through each year for each facility for each resource type in the above manner. Finally, resources of each type are summarized for the whole energy system for each year.

OPERATIONS RESOURCE REQUIREMENTS GENERATORS

Function

The Operations Resource Requirements Generators specify the annual requirements of manpower, materials, and equipment for the normal operation and maintenance of energy-related facilities at the national level. The purpose is to provide integrated, system-wide operations resource requirements for any fuel mix, based on the annual schedule of total on-line facilities. The calculations are carried out separately for energy supply and transportation facilities, but the logic is identical.

In addition, the computing capability exists for processing additional data associated with the operation of energy facilities. One such type of data currently being processed is energy resources consumption data. The computing machinery is designed to process additional data on environmental information (air pollutants, water pollutants, radioactive emissions, land and water requirements) and raw energy inputs to the energy system when these data are available.

Method

Because operations data are assumed to be time-invariant for each facility, the approach is quite straightforward. The total number of facilities of a given type existing in a given year are multiplied by the annual operations resource requirements to get total resource requirements for all facilities of that type in the year of concern. The total number of facilities is obtained by the updated facility vector (time-shifted) calculated in the National Energy Facilities Generator. These requirements are calculated for each individual facility type and for the whole energy system.

Input and Output Structures

Figure 3-11 summarizes the input and output structures of the Operations Resource Requirements Generators. Inputs include:

- Annual schedules for 1974 to 1985 of total on-line facilities (66 energy supply and 24 energy transportation facilities)
- Facility resource requirements data (115 categories) for energy supply (66) or transportation (24) facilities.

Outputs are the annual schedules (1974 to 1985) of resources required for the normal operation and maintenance of energy supply or transportation facilities.

Figure 3-11. Input and Output Structures of Operations Resource Requirements Generators

Section 4

METHODOLOGY - REGIONAL MODEL

An overview of the Energy Supply Planning Model is presented in Section 2, followed in Section 3 by a detailed description of the national model methodology. This section describes in detail the calculations necessary for a regional run sequence. After a general description, it describes in turn each submodel of the sequence. These are:

- The Fuel Mix Generator
- The National Energy Facilities Generator
- The Regional Energy Facilities Generator
- The Interregional Fuel Flow Generator
- The Interregional Transportation Facilities Generator
- The Construction and Operations Resource Requirements Generators

REGIONAL MODEL DESCRIPTION

The sequence of operations outlined in Figure 4-1 converts a given future energy mix into a schedule of energy supply and transportation facilities necessary to supply that energy mix and calculates the total direct resources required to bring on-line and to operate the facilities, at a regional level of detail.

The primary motivations for development of this regional analytic capability are two-fold:

- Resource Requirements. Regional resolution of requirements for certain resource categories (e. g. manpower) is required to provide greater insight into

Figure 4-1. The Regional Model: Methodology Overview, Inputs and Outputs

institutional, societal, and environmental impacts of future energy developments. This type of information is becoming increasingly valuable to states and regions concerned about the effects of national energy programs on their areas.

- Transportation System Accuracy. The energy transportation system has by its nature a regionally-defined structure and function. Analysis of transportation facility and associated resource requirements at the regional level is necessary to provide a finer approximation of the requirements, derived from a regional disaggregation of supplies and demands.

The following paragraphs detail the methodology developed for each submodel associated with the regional run sequence of Figure 4-1. Systems programming aspects of the sequence are described in Volume II.

FUEL MIX GENERATOR

The Fuel Mix Generator is described extensively in Section 3. As in the national modeling sequence, the primary purpose of the Fuel Mix Generator is to convert user inputs into a form suitable for the subsequent calculation of national energy supply facility requirements. In addition, information not available elsewhere is created for direct use by certain of the regional submodels. This information includes primarily the specification of:

- Coal sources for synthetic fuels, disaggregated as high- and low-Btu coal
- Refined products imports from Canada

The input to this submodel is the most significant input to the regional model just as it was for the national model. For regional analysis, certain of the fuel mix user input variables take on special significance because of the regional information specified by them. The most significant of these variables include:

- Fractions of oil and gas supplied from onshore, offshore, Alaskan, and foreign sources.

- Fractions of coal for direct use and for synthetic fuel facilities from underground Eastern, surface Eastern, underground Western, and surface Western sources
- Fraction of coal-fired power plants using low-Btu coal (only the nominal surface Western coal mine produces low-Btu coal)
- Fractions of coal-fired power plants using high-Btu coal from underground Eastern, surface Eastern, and underground Western coal sources

NATIONAL ENERGY FACILITIES GENERATOR

The National Energy Facilities Generator is also described extensively in Section 3. As in the national model, the submodel calculates the annual schedules of energy supply facilities needed on-line to satisfy the fuel mix, at the national level. Unlike the situation in the national model, the function here is to generate national facility requirements that can be used in the subsequent calculation of regional facility schedules. Required national schedules are determined both for additions, from which are derived new additions in each region, and for the total number of facilities on-line, from which are derived on-line facilities in each region.

In addition to the primary function described above, other information not available elsewhere is derived for use by certain of the regional submodels. This information includes:

- Distillate and heavy fuel oil yields of low-gasoline refineries
- Overland imports of crude oil
- Alaskan crude oil flows
- Oil product imports through onshore oil import facilities
- Facility lifetimes and retirement data

REGIONAL ENERGY FACILITIES GENERATOR

Function

The function of the Regional Energy Facilities Generator is to distribute the annual schedules of additions and on-line totals of energy supply facilities, calculated in the National Energy Facilities Generator, among the 14 different geographic regions of the model (Figure 2-4). The regional schedule of additions is needed for the subsequent calculation of regional resources required for the construction of energy supply facilities. The regional schedule of on-line totals is needed both for the derivation of transportation facility requirements and for the subsequent calculation of regional resources required for the operation and maintenance of energy supply facilities.

Schedules of additions in each of the 14 regions are derived directly from user-specified energy facility location coefficients, which specify the fraction of new facilities of the various types that are to be located in each of the regions, as a function of time. Missing input variables are supplied by default values generated by the study team. These user inputs are transformed into regional facility schedules according to the rules specified by the methodology that follows. The user input interface is described in Section 5.

Method

The method involves regionalizing the national schedules of additions of energy supply facilities of the various types by application of user-specified energy facility location coefficients. An integer number of facilities are added to each of the 14 regions by use of appropriate round-off methods. After round-off, the number of additions in each region is added to the previous year's existing facilities, that have been adjusted for retirements to obtain the updated on-line totals in each region.

The round-off methods assure that the regional additions are integers and that the sums over the regions track the national additions. One of two types of round-off procedures is used, and the appropriate one is selected by the user for each facility. Type I procedure applies to facilities that may be considered to have their requirements determined solely by national demands (e. g. the need for oil wells is determined on the basis of a national rather than a regional oil demand). The Type II procedure assumes that the facility is strongly influenced by regional demands (e. g. power plants).

For Type I facilities the regional facility increments are rounded off so that the sum of the facilities over all regions exactly equals the number of national addition. This is accomplished by assigning an integer number of facilities to the regions with the largest fractional requirements until the national total is met. The remaining unsatisfied fractional requirements are carried into the future until they are large enough to attract a whole facility. Ties are broken randomly.

The round-off procedure for Type II facilities allows the user to pick the fractional level above which a facility will be automatically assigned to a region. In this procedure the sum over all regions for a given year may not equal the national total (reflecting a slight over-capacity or under-capacity), but will even out over time because the remaining fractional requirements that are not rounded up are carried into the future until they are large enough to justify a whole facility. Excess capacities — the difference between the rounded-up values and the fractional requirements — are also tracked from one time period to the next for both types of facilities.

Special calculations are required for the treatment of certain facilities.

These include:

- Oil-to-coal reconversions
- Facilities that receive Alaskan fuels
- Import facilities

Input and Output Structures

The input and output structures of the Regional Energy Facilities Generator are illustrated in Figure 4-2.

Major inputs include:

- Nationally-aggregated annual schedules of new additions of energy supply facilities (66) for 1974-1995
- Nationally-aggregated on-line facility totals of energy supply facilities (66) for 1973 only
- User-specified energy facility location coefficients (66 facilities and 14 regions) as a function of time at user option

Figure 4-2. Input and Output Structures of the Regional Energy Facilities Generator

Major outputs include:

- Annual schedules of new additions of energy supply facilities (66), distributed into 14 regions, 1974-1995
- Annual schedules of on-line totals of energy supply facilities (66) distributed into 14 regions for 1973 to 1995

Computational Logic

Basic Logic. The logic is basically a three-step procedure for each cycle of computation, carried out annually for 1974 to 1995, wherein the required number (fractional) of new energy supply facilities are determined for each region. The additions are rounded up or down to determine actual additions for each region, and updated on-line facility totals are calculated.

The set of energy supply facilities are first partitioned into two types of facilities (user option) as follows:

- Type I. Regional additions must sum to national additions, i. e. required capacity is determined at the national level.
- Type II. Regional additions need not sum to national additions but should yield a reasonable approximation, i. e. required capacity is determined at the regional level.

Each set of facilities is handled by a separate round-up procedure. For Type I facilities, the major steps in determining regional additions for each year are noted below:

- National increments are multiplied by the energy facility location coefficients to determine requested facilities in each region for the various facility types.
- Each region gets at least the number of whole facilities requested.

- The remaining capacity (made up of "requests" for fractional facilities) is allocated to the regions requesting the largest partial facilities (ties are broken randomly) until the total number of regional additions exactly equals the national total.
- Excess or deficient capacity is carried forward regionally for adjustment in the next year.

For Type II facilities the major steps in determining regional additions include:

- National increments are multiplied by the energy facility location coefficients to determine requested facilities for the various facility types.
- Noninteger facility requests are rounded using a user-specified threshold value α by the rule: "If the fractional part of the request is greater than α (α is between 0 and 1), round up. If it is less than α , round down." This procedure is executed regardless of whether the total number of regional additions equals the national total.
- Excess or deficient capacity is carried forward regionally for adjustment in the next period.

Regardless of the type of facility, the total numbers of facilities on-line in each region are updated following determination of the new additions. This is carried out by adding the number of new additions to the previous year's number of existing facilities and adjusting downward for retirements during the previous year.

Special Cases. Special logic is required for accurate treatment of certain facilities.

- Reconversions of Oil-Fired Power Plants to Coal. Since reconversions of oil to coal power plants involve the loss of oil-fired capacity, a special calculation is needed to avoid double counting. This is accomplished by a step performed after the regional schedule is complete which adjusts existing oil power plants for the cumulative losses due to reconversions.

Note that this calculation only affects the total number of oil power plants. It does not affect the regional schedules for coal-fired power plants, coal reconversions, or new additions of oil-fired power plants.

- Alaskan Imports. It is assumed that all Alaskan exports are imported through onshore California (region 11) ports. A special calculation is therefore performed on the energy facility location coefficients to assure that the distribution of import facilities (oil and LNG) is adequate to handle Alaskan production by relating Alaskan exports to California imports over time. This results in an adjusted set of coefficients for the two types of onshore ports.
- Operating Levels of Port Facilities. In calculating the capacity available to supply fuel requirements, the regional model assumes that facilities may operate at full capacity. In most cases, the operating level of facilities will be slightly less than the existing capacity of facilities because of integer round off in the addition of new capacity. Exceptions to this arise from consideration of fuel import facilities (onshore oil import facilities, offshore crude oil import facilities, LNG import facilities) because "excess capacity" in these very large facilities could distort the model's view of the available supply of oil or gas in port regions. The potential problem would be exaggerated by scenarios that decrease U.S. dependence on foreign oil and gas sources, and excess capacity would increase.

INTERREGIONAL FUEL FLOW GENERATOR

The function of the Interregional Fuel Flow Generator is to convert the distribution of energy supply facilities in the 14 model regions, calculated by the Regional Energy Facilities Generator, into fuel flows within and among regions for the subsequent calculation of energy transportation facility requirements.

There are two essential steps in the calculation:

- The facilities-to-fuels transformer converts facility locations into the location of fuel supplies and demands
- The fuel flow allocator allocates the regional supplies of fuels to the regional demands

User-specified inputs of regional demand coefficients and interregional fuel flow rules are employed to convert the energy supply facility mapping to the fuel flow network required for the derivation of energy transportation facility requirements.

Facilities-to-Fuels Transformer

Function. The facilities-to-fuels transformer is designed to convert the output of the Regional Energy Facilities Generator to an appropriate form for input to the fuel flow allocator. That is, information related to the total number of facilities in any specific region is transformed into information related to fuel supplies and demands in that region. This transformation is necessary to derive transportation facility requirements from fuel flow information.

Method. The facilities input and output fuels are aggregated into fuel types appropriate for use in the fuel balancing algorithm of the fuel flow allocator. Based on nominal facility descriptions and the fuel aggregations just described, facilities fuel input and fuel output matrices are developed. The facilities-to-fuels transformer multiplies the regional facilities matrix (total number of facilities of various types operating in the various regions) by the facilities fuel output matrix to obtain the regional fuel supply matrix and, similarly, multiplies the regional facilities matrix by the facilities fuel input matrix to obtain the regional fuel demand matrix. Additional terms are added to account for imports

and final fuel demands. To obtain regional final fuel demands, user-specified (or default) regional demand coefficients are multiplied by national final fuel demands from the Fuel Mix Generator. Certain facilities cannot be treated simply by multiplying their nominal inputs and outputs by the total number in a region; these special cases are described later in this section. The supply and demand matrices are calculated for each year from 1973 through 1990.

Input and Output Structures. Figure 4-3 shows a diagram of the input and output structures of the facilities-to-fuels transformer. The primary input is the regional facilities matrix with dimensions of 66 facilities by 14 regions for each year from 1973 through 1990. Another input is two matrices providing nominal facilities definitions. These two matrices, one for facility input flows and the second for facility output flows, have dimensions of 66 facilities by 11 fuel types. Additional inputs, such as national final fuel demands and overland imports, are obtained from the Fuel Mix Generator. These and other required inputs are described later in this section. The output of the facilities-to-fuel transformer consists of regional supplies and demands of energy fuels. These two output matrices have dimensions of 14 regions by 11 fuel types and are calculated for each year from 1973 through 1990.

Fuel Type Definitions. The various fuel inputs and outputs of the facilities are aggregated into 11 fuel types which are defined so that the fuels in each type may be treated in a similar manner in balancing fuel supply and demand.* Fuel type definitions and the units of measure for nominal facility inputs or outputs are shown in Table 4-1.

* Regional location of all energy supply facilities is considered in the regional model; however, the regional flows of certain fuels are not considered. These fuels, which are neither allocated based on regional supplies and demands nor transported, are: nuclear fuels, low-Btu gas, and "all other products" (such as lubricating oil, paraffin wax, etc.).

Table 4-1

FUEL TYPES

Fuel Type No.	Fuel Type Name	Units	Definition
1	Crude Oil	MMBPD	Includes crude oil from lower-48 onshore and offshore oil production, Alaskan oil production, upgraded shale oil, imported overland and overseas oil, and the natural gas liquids byproduct from Alaskan gas production
2	Motor gasoline	MMBPD	Includes motor gasoline from low- and high-gasoline refineries and coal liquids refinery, imported overland and overseas motor gasoline
3	Distillates	MMBPD	Includes distillates from low- and high-gasoline refineries and coal liquids refinery, imported overland and overseas distillates
4	Other products	MMBPD	Includes jet fuels, kerosenes, and other light products (naphtha, natural gas liquids, etc.) from low- and high-gasoline refineries and coal liquids refinery; imported overland and overseas other products; natural gas liquids from onshore and offshore gas production facilities
5	Methanol	MMTPD	Includes methanol from coal gasification (methanol) facility, imported overland and overseas methanol
6	Heavy fuel oil	MMBPD	Includes heavy fuel oil output from low gasoline refineries and coal liquefaction facility, imported overland and overseas heavy fuel oil
7	Electricity	GWe	Includes electricity produced from all power plants, imported electricity
8	High-Btu coal	QUADBtu/Y	Includes high-Btu coal from Eastern underground and surface coal mines and Western underground coal mines, imported high-Btu coal
9	Low-Btu coal	QUADBtu/Y	Includes low-Btu coal from Western surface coal mines, imported low-Btu coal
10	Solvent refined coal	QUADBtu/Y	Output from coal solvent refining (SRC) facility
11	Natural gas	TCF/Y	Includes lower-48 onshore and offshore gas production and Alaskan gas production; imported overland and overseas natural gas; natural gas output from lower-48 onshore and offshore oil production and Alaskan oil production; output from coal mine degasification facility and outputs from coal gasification (high-Btu), naphtha gasification, and heavy fuel oil gasification facilities

Figure 4-3. Facilities-to-Fuels Transformer

Computational Logic. The computational logic used in the facilities-to-fuel transformer is arranged to handle both basic and special cases.

- **Basic Logic.** The regional fuel supply matrix is obtained by multiplying the regional facilities matrix by the nominal facilities output matrix, adding overland fuel imports, and adding other terms to express the output of facilities which must be treated separately.*

$$[B_{mp}] = [A_{mn}] \cdot [O_{np}] + [OL_p] + [\text{other terms}]$$

where B_{mp} = total output flow of fuel type p from all facilities located within region m

A_{mn} = regional facilities matrix entries, total number of n^{th} type facility located in region m, (information obtained from the Regional Energy Facilities Generator)

O_{np} = output flow of fuel type p for one nominal facility type n (facility definition data contained in this section of the model)

* See discussion of special cases.

- OL_p = overland imports of fuel type p from Canada (information obtained from the the Fuel Mix Generator for fuel types 2 to 11 and from the National Energy Facilities Generator for fuel type 1)
 m = region number, $m = 1 \dots 14$
 n = energy supply facility type, $n = 1 \dots 66$
 p = fuel type, $p = 1 \dots 11$

The regional fuel demand matrix is obtained by multiplying the regional facilities matrix by the nominal facilities input matrix, adding regional fuel final demands, and adding further terms to express the input to facilities which must be treated separately.

$$[C_{mp}] = [A_{mn}] \cdot [I_{np}] + [D_{mp}] + [\text{other terms}]$$

- where C_{mp} = total input flow of fuel type p to all facilities located within region m
 I_{np} = input flow of fuel type p for one nominal facility of type n (facility definition data contained in this section of model)
 $D_{mp} = E_p d_{mp}$
 = final demand for fuel type p in region m
 E_p = national final demand for fuel type p (information obtained from Fuel Mix Generator)
 d_{mp} = regional demand coefficients, the fraction of final demand for fuel type p in region m (reference values for these coefficients contained in this section of the model, the user may specify a different set of coefficients if he desires)

The two matrices $[E_{mp}]$ and $[C_{mp}]$ are the outputs of this section of the model and represent regional fuel supplies and demands for the various fuel types. They are passed to the fuel flow allocator to be used in balancing fuel supplies and demands.

- Special Cases. Special logic is required to treat those facilities that have fuel inputs or outputs that vary from fuel mix to fuel mix and for stockpile facilities.

- Onshore Oil Import Facility (Facility No. 11). The onshore oil import facility is defined by a nominal total products capacity of 0.959 MMBPD. The amount of each of its six possible product types output (fuel types 1, 2, 3, 4, 5, and 6) may vary with both time and region.

The output yield of heavy fuel oil, 0_{11,6}, for onshore oil import facilities in regions 1, 2, and 3 is calculated by dividing the total national overseas imports of heavy fuel oil by the total number of facilities in regions 1, 2, and 3. The output yield of heavy fuel oil for all other regions is set equal to zero. The output yield of motor gasoline, distillates, other products, and methanol (i. e., fuel types 2, 3, 4, and 5) is calculated by dividing the total national overseas imports of each of these fuels by the total number of facilities in all regions. Finally, the output yield of crude oil, fuel type 1, is obtained in each region by subtracting the sum of the yields of fuel types 2 through 6 from the nominal total products capacity of the onshore import facility. Levels of total national overseas imports are obtained from the Fuel Mix Generator, and regional facility totals are obtained from the Regional Energy Facilities Generator.

- Low-Gasoline Refinery (Facility No. 5). The low-gasoline refinery has the following four outputs: motor gasoline, distillates, all other products, and heavy fuel oil, i. e. fuel types 2, 3, 4, and 6 respectively. The yields of distillate and heavy fuel oil may vary with time, since distillate may be blended to produce more heavy fuel oil during periods when it is in high demand. The values for 0_{5,3} and 0_{5,6} are supplied by the National Energy Facilities Generator where this blending decision is made. This nationally determined yield of low-gasoline refineries is used for all regions.

- Oil-Fired Power Plant, High-Btu Coal-Fired Power Plant, Combined-Cycle Power Plant, Gas-Turbine Power Plant, and Fuel Cells (Facilities Nos. 47, 50, 56, 57, 58). These five power plant types have multiple alternative inputs, e. g. the input to the

oil-fired power plant (No. 47) can be either crude oil (fuel type 1) or heavy fuel oil (fuel type 6). Data obtained from the Fuel Mix Generator specifies the fraction of the required total national input to these facilities that was met by each possible alternative fuel in the given fuel mix. It is assumed that this national percentage may be used for each of the regions.

- Coal Gasification (High-Btu), Coal Gasification (Low- and Medium-Btu), Coal Gasification (Methanol), Coal Liquefaction (Heavy Fuel Oil), and Coal Solvent Refining (SRC) (Facilities Nos. 27, 28, 29, 30, 31). These five facilities also have multiple alternative inputs (for all five facilities the inputs are either high- or low-Btu coal) and are treated generally in a manner similar to that described above, except that the Eastern and Western regions are treated separately. For example, for Facility No. 27, coal gasification (high-Btu) located in the Western region, the fraction of input supplied by high-Btu coal, fuel type 8, is approximated by calculating the ratio of coal supplied to Facility No. 27 from Western underground and surface mines. In the Eastern regions, it is assumed that all of the required input will be supplied by high-Btu coal.

- Crude Oil Stockpile and Natural Gas Stockpile (Facilities Nos. 8 and 22). Special logic is required for stockpile facilities because fuel does not flow through these facilities; once filled, they stay filled. Fuel flows are determined not by the total number of facilities on-line but by the number added since the previous year.

The total input flow of crude oil to the crude oil stockpile and of gas to the natural gas stockpile for each region for a specified year is calculated in the following manner. The total amount of fuels to be added to the two types of stockpiles in a specified year is obtained from the Fuel Mix Generator. The number of new stockpiles built in each region to accommodate this new stockpile requirement is obtained from the Regional Energy Facilities Generator. The input flows for each region are obtained by first filling the last partially filled stockpile, then proceeding to fill the newly built stockpiles.

The last newly built stockpile may be only partially filled; this is the stockpile that will be filled first when there is an additional requirement for fuel to be stockpiled in the next year.

Fuel Flow Allocator

Function. The fuel flow allocator is designed to convert information about regional fuel supplies and demands into flows of fuel from origins to destinations, based on user-specified (or default) fuel flow rules. The objective is to generate flows of fuels from which future energy transportation facility requirements can be derived.

Method. Fuel flows are allocated not by use of optimization techniques but rather by a heuristic approach that seeks to allocate supply sources to demand centers on a proximity basis. The heuristic method employs user-specified fuel flow rules to carry out the allocation rather than internally-generated criteria. This approach allows the interested user the flexibility to simulate any future fuel flow network.

Each fuel is considered separately. For any given fuel, the model first chooses a demand region, then a region to supply the demand region, then a quantity of fuel to flow from source to destination. It then revises regional quantities by unused supply and unmet demand, continuing until all supply is exhausted or all demand is met.

The model meets each regional demand for fuel by allocating supplies to the region in a four-step sequence as follows:

- Allocation of available local supplies (within the region) to the demand
- If the demand is not yet satisfied, allocation of available supplies from nearby (or otherwise favorable) regions to the demand

- If the demand is still not satisfied, allocation of available supplies from less-favorable regions to the demand
- If the demand remains unsatisfied, allocation of available supplies from any region to the demand

The set of user input (or default) instructions consists of specifying which of the 14 model regions are to be considered favorable supply regions and which are to be considered less-favorable for each fuel demand region. The user can control the allocation both by specifying the above search pattern and by specifying the fraction of a region's remaining supply that may be allocated each time it is tapped as a source.

Input and Output Structures. Figure 4-4 shows the input and output structures of the fuel flow allocator. Inputs include:

- Supplies of fuels (11) in each region (14 domestic plus imports) annually 1973-1990

Figure 4-4. Input and Output Structures of the Fuel Flow Allocator

- Demands for fuels (11) in each land region (11) annually 1973-1980
- User-specified or (default) fuel flow rules for each fuel (11) and each demand region (11)

Outputs are the quantities of fuel (11) for each origin-destination pair ($15 \times 11 = 165$) for the years 1973, 1977, 1980, 1985, and 1990. Two features are worthy of note. First, results are calculated for selected years rather than annually to reduce the computational requirements for the subsequent derivation of transportation facility requirements. It was felt that the high dimensionality of the transportation submodel was sufficient to warrant this aggregation. Second, fuel flows are computed through 1990 rather than 1995. The end date of 1995 has been used previously because the objective of calculating construction resource requirements through 1985 necessitates carrying facility on-line dates far enough into the future to allow for facility construction periods. Certain energy supply facilities have lead times of up to 9 years; hence on-line requirements through at least 1994 are needed. However, no energy transportation facility has a construction period longer than 5 years; accordingly, the end date of 1990 is adequate for calculating these requirements.

Computational Logic. The fuel flow allocator generates flows among regions by proceeding through the demand regions in an ordered fashion, in each case searching for available supplies within its own region first and then among three sets of priority supply regions.

The criteria used in choosing the order of filling demands and the order of choosing supplies within each priority set are fixed internally. In each case, the model selects the region with the largest unsatisfied demand or the largest available supply within the priority supply set under consideration. That is, the routine will choose the largest unmet demand, find

the largest quantity in its supply set under consideration, and make the appropriate allocation. It then updates the demand and supply and again searches for the largest unmet demand. Iteration continues until a maximum demand or a maximum supply is zero, indicating that all demands are met or all supplies are allocated. This cycle is repeated for each fuel for each of the years 1973, 1977, 1980, 1985, and 1990.

This allocation scheme is constrained by three user-specified controls:

- The fraction of a region's demand that can be met from its own supplies (intraregional) before searching for priority regions
- The fraction of a region's supply it can use to meet its own (intraregional) demand prior to searching for supply among its priority regions
- The fraction of a region's remaining supply yielded to a demand region when tapped (interregional)

The interregional search pattern is specified by user (or default) partition of the set of all supply regions into three priority sets for each demand region. In general, placing regions in the same priority set for a given region indicates indifference among those regions as fuel sources for the demand region under consideration. The user-specified members of the first priority set can be thought of as the preferential sources for fuel supply for the given demand region. For example, for coal, Region 2's first priority sources might be Regions 3, 4, and 5. The model is restricted to tapping each source in the first priority set once, before searching the second priority supply set.

The second set operates in a similar manner and also consists of a user-specified set. The first priority regions are automatically included in the second priority set; the user need only specify the augmenting supply regions. When every source in the second set has been tapped once, the search passes to the third set.

The third priority set automatically includes all 14 regions and is included to allow feasibility in satisfying demands if searching through all priority regions leaves unsatisfied demands.

The heuristic model described above gives the user extensive flexibility in controlling the flows of fuels. Preliminary experience indicates that nearly any desired fuel flow pattern can be simulated through an iterative process of fine-tuning the user controls and priority sets.

INTERREGIONAL TRANSPORTATION FACILITIES GENERATOR

Function

The primary function of the Interregional Transportation Facilities Generator is two-fold: first, to calculate a schedule of required annual additions to capacity for each of the 25 transportation facilities in each region for use as an input to the Construction Resources Requirements Generator^{*}; second, to calculate an annual schedule of existing facilities in each region for each of the facilities under consideration, for use as an input to the Operations Resources Requirements Generator. These facility schedules are calculated by using regional flows of fuels from the Interregional Fuel Flow Generator, the transportation system definition, along with user-specified (or default) interregional transportation modal-split coefficients.

Method

Calculations follow a sequence of five steps, shown in Figure 4-5. First, the total flow of any given fuel between origin-destination (O-D) pairs is allocated to the transport modes available to that fuel by one of three algorithms. Then, based on the haul length and the nominal facility

^{*} In the regional model, resource requirements data have been developed for 25 rather than 24 nominal transportation facilities. This difference is due to disaggregation of coal slurry preparation and dewatering facilities into two separate facilities to account for the likelihood that they may be built in different model regions.

Figure 4-5. Interregional Transportation Facilities Generator

definition, the number of transportation facilities of each type required to carry the flow is calculated. Facilities existing during the previous year are adjusted for retirements expected over the course of the current year. The adjusted number of facilities is compared to the required number, and an integer number of facilities is built to make up the difference, if necessary. The existing facilities at the end of the year are obtained by summing the adjusted number of existing facilities and the incremental additions to capacity for that year. The user may specify a threshold value, the minimum fraction of a facility required before one is built. Should a transportation mode be used for more than one fuel (conventional trains can carry both oil and coal, for example) the number of required facilities for each fuel are summed to yield the total number

of required facilities. Finally, transportation facilities (incremental and existing) are assigned to the various regions where they exist.

All computations are performed using O-D pairs. It is only at the final stage of the model that facilities by O-D pairs are distributed to the regions.

Because of the diversity of the fuels and transportation modes considered, three unique modeling approaches were used to determine modal flows.

The use of certain modes between O-D pairs must be explicitly specified by the user because of the uncertainty in use of the mode (e.g., 400 kV DC electric transmission lines and coal slurry pipelines). In these cases, the user must specify the percentage of flow between O-D pairs to be transported by these modes. The remainder of the flow is handled by one of the two other algorithms discussed in this section.

An incremental modal-split approach is used for fossil fuel transportation. Base year (1973) flows by mode are determined by modal-splits input for 1973. For succeeding years, any increase (or decrease) in flows between O-D pairs is allocated by user input of the incremental modal-split coefficients. This approach results in a time-dynamic formalism, i.e. the algorithm adjusts for changing flow patterns.

A threshold algorithm that approximates a least-cost decision criterion is used to select facilities for the interregional transmission of electricity. The Federal Power Commission has published statistics showing that each EHV transmission line (230 kV, 345 kV, 500 kV, 765 kV, 765 kV) has a power loading range over which it is the economically attractive mode. These ranges are used as thresholds over which the algorithm allocates modes, based on incremental requirements for electric transmission facilities.

Requirements for the intraregional transmission of electricity are calculated using the incremental modal-split approach described for fossil fuel transportation.

Each of the three approaches accomplishes the same goal: to specify modal flows between O-D pairs. These flows are then handled in the general manner described above to yield the specification of transportation facilities requirements.

Transportation System Descriptive Data

The function of the Interregional Transportation Facilities Generator is to compute required additional facilities; hence, accurate estimates of existing 1973 facilities are needed. Data describing the existing energy transportation system in general and coal transportation in particular have been found to be most inadequate for the purpose of this model. No accurate existing capacity figures seem to be available for coal. The complexity of developing such information is considerable. For example, significant variables in determining existing rail line capacity include but are not limited to the existence of single or double track, the condition of the track, use of track for shipments of other commodities, signaling facilities, yard bottlenecks, and peak demand considerations. In addition, determination of requirements for additions of rail line capacity is complicated by the number of ways in which capacity can be increased, e. g. a spur line may be built, poor sections of track can be upgraded, bypasses may be constructed around bottlenecks, main trunk lines may be added, etc. It was not the intent of this study to develop such information. If available, however, its existence would significantly improve coal transportation analysis. Hence, coal-related results of this modeling analysis should be indicative of trends in new capacity requirements but not taken as specific statements of needed new capacity additions.

Input and Output Structures

As shown in the Interregional Transportation Facilities Generator schematic, Figure 4-5, there are three basic sets of inputs to the model. The first set is the output of the Interregional Fuel Flow Generator: the flow of fuel by fuel type (a total of 12) by O-D pairs (a total of 165) for the years 1973, 1977, 1980, 1985, and 1990.

The second input is the user-specified interregional transportation modal-split coefficients. The third input is the reference transportation system definition (haul lengths, capacities, regional data, etc.). There is a total of approximately 14,000 incremental modal-split coefficients that the user may change by specifying approximately 480 general coefficients. By specifying up to 80 general coefficients, the user may adjust all of the major incremental modal-split coefficients. This interface is described more fully in Section 5.

There are two basic sets of outputs available to the user. The most directly useful output consists of annual regional schedules of incremental additions to capacity and of existing facilities. Secondary outputs accessible by the user are annual schedules of required incremental and existing facilities by origin-destination pairs.

Fuel Type Definitions

The 12 fuels used in the Interregional Transportation Facilities Generator are listed in Table 4-2. It differs from the fuels used within the Interregional Fuel Flow Generator because the Fuel Flow Generator requires a stricter definition of fuels than does the Transportation Facilities Generator, and because the transportation model requires imports by sea to be identified separately to compute tanker requirements.

The fuels considered in the model fall into one of three general categories: continental U.S. produced fuels, imported overseas fuels, and Alaskan fuels. Continental flows include all flows within the continental U.S. That is, imports and Alaskan fuels are considered indistinguishable from domestic production upon reaching the U.S. Imports are considered separately only for the purpose of determining tanker requirements; Alaskan fuels are considered separately to determine pipeline and tanker requirements. Refined products are the sum of gasoline, distillate, methanol, and other products as defined in the Interregional Fuel Flow Generator. Also, high-Btu coal, low-Btu coal, and solvent refined coal fuels are summed to produce the fuel "Coal" used in the Interregional Transportation Facilities Generator.

Table 4-2

INTERREGIONAL TRANSPORTATION FACILITIES
GENERATOR FUEL TYPES

No.	Fuel	Units
1	Continental crude oil	MMBPD
2	Imported foreign crude	MMBPD
3	Alaskan crude	MMBPD
4	Continental refined products	MMBPD
5	Imported refined products	MMBPD
6	Continental heavy fuel oil	MMBPD
7	Imported heavy fuel oil	MMBPD
8	Continental gas	TCF/Y
9	Imported gas	TCF/Y
10	Alaskan gas	TCF/Y
11	Coal	MMT/Y
12	Electricity	GWe

Computational Logic

Transportation of Fossil Fuels. The determination of transportation requirements for fossil fuels is performed in a sequence of steps detailed below.

Fuel Flows by Mode. Determination of the modes by which a given fuel flow will travel is a complex task. Since future mode choices depend on past choices, a time-dynamic formulation using the following heuristic was adopted.

The total amount of fuel to travel by some mode in a given time period is equal to the amount that traveled by that mode the previous time period plus a fraction of that fuel's incremental flow during the period.* This fraction is called the incremental modal split (R). Two R's are specified: one for increases in incremental flow (R+); the other for decreases in incremental flow (R-).

In the special case of the base year, flows by different modes are computed by multiplying the base year flow by the base year modal-split.

Coal slurry pipelines are treated in a special way because of their infrequent use in the current transportation system. Thus, for coal, the user must specify the fraction of coal to be transported by this mode between specific O-D pairs. The model then subtracts this amount from the total fuel transported between the regions and proceeds as above.

Once the fuel flow has been assigned among the various modes of transportation, the remainder of the algorithm is very similar to that of the National Transportation Facilities Generator, except for the added complexity of handling O-D pairs. It proceeds as follows:

* The Fuel Flow Generator may generate very small flows between widely separated O-D pairs to meet feasibility conditions. These flows should not be considered in determining required facilities. The transportation model arbitrarily eliminates from further consideration any flow less than five percent of the maximum flow between O-D pairs of that fuel in that year.

- Fuel/Mode Transportation Facility Requirements. First, the required number of facilities is calculated by dividing the product of the flow and haul length by the nominal capacity of the facility.
- Total Transportation Facility Requirements. A mode may carry more than one type of fuel. For example, oil tankers may carry crude oil, refined products, and heavy fuel oil. The requirements for any transportation mode must then be summed to give total capacity required pertaining to each mode.
- Yearly Facility Requirements. Up to this point, facility requirements have been calculated for the years 1973, 1977, 1980, 1985, and 1990. These periodic values are interpolated to determine required facilities by year, 1973 to 1990.
- Needed Additional Facilities. Facilities in existence the previous year must be adjusted for retirements over the course of the current year. (Facilities existing in 1973 are retired at a time-dependent annual rate.) The adjusted figure is then subtracted from the number of required facilities. The result is the number of needed additional facilities.
- Update Existing Facilities. The number of facilities to be built in the current year is now known. To compute the facilities existing at the end of the current year requires only adding the number of incremental facilities for the current year to the adjusted number of facilities existing the previous year.

For the special case of the base year (1973), the number of required facilities is considered to equal the number of existing facilities.

- Distribute Incremental Facilities Among Regions. Thus far, all computations have been based on O-D pairs. The numbers of incremental and existing facilities by region are also needed. Mobile transportation facilities such as trains, trucks, tankers, etc., are assigned to the destination region. For all other facilities (pipelines, rail, etc.), this is done through use of regional share coefficients by mode for each region through which a line connecting the O-D pair passes. Currently, this apportionment is done on the basis of distance: If 10 percent of the line between Region A and Region B lies in Region C, then 10 percent of the facilities between A and B will be allocated to Region C. Facility requirements are then summed over all O-D pairs to yield total regional facility requirements. Existing facilities are allocated in an identical manner.

Transmission and Distribution of Electricity. Selection of line voltages for electric transmission is a complex task; many factors affect the choice. The heuristic for electric transmission uses a threshold algorithm that approximates a least-cost criteria. The Federal Power Commission has published statistics indicating that each commonly used EHV line size has a range of power loadings over which that line size is economical. Table 4-3 gives the threshold values used.

Table 4-3

THRESHOLD VALUES ALGORITHM FOR EHV SELECTION

Power Transmitted (GWe) Between an O-D Pair	Use EHV Line (kV)
0 to .31	230
.31 to .90	345
.90 to 1.71	500
Greater than 1.71	765

The present heuristic proceeds by first computing incremental flows of electricity and then assigning these flows to the least-cost transmission mode for that power loading. This selection is based on the definition of incremental flows. All lines are used to capacity before another is built. An incremental flow is the difference between the flow of electricity between an O-D pair and the total capacity of all transmission lines to carry it. Thus, behavior whereby a utility builds a 765 kV line, for example, with future increases in mind and retires a 345 kV line is not modeled.

The least-cost algorithm described above is adequate for long distance, interregional electric power transmission. For short distance, intra-regional transmission, a conventional modal-split model is used. User-specified (or default) modal-split values for each region for the years 1973, 1977, 1980, 1985, and 1990 are used to determine the flow-by-mode of electric power within the region. The required number of

facilities, the incremental number of facilities, and so forth are computed in a manner identical to that used in the fossil fuel method.

No retirement of existing facilities is allowed in the electricity model because of the long lifetime of each facility and the relatively recent introduction of EHV transmission.

To specify where 400 kV DC lines are to be built, the user specifies the fraction of flow between specific O-D pairs that will be transmitted by DC lines. Any DC transmission lines built will add to the transmission capacity between those O-D pairs when computing the next year's incremental flows.

Required electrical distribution facilities are calculated by dividing the electrical demand in each region by the capacity of a nominal facility. An integer number of facilities are built, if necessary. (Again, no retirements are allowed.) The existing capacity is then updated and the cycle begins again.

CONSTRUCTION RESOURCE REQUIREMENTS GENERATORS

The Construction Resource Requirements Generators specify the requirements of capital, manpower, and materials (77 categories) for the construction of each energy supply and transportation facility and for the whole energy system for each of the 14 model regions, annually for the years 1974 through 1985. Essentially, the logic is identical to that discussed earlier in the national model methodology of Section 3. * Major

* The logic described in the national model methodology for accounting for system lead time effects is ignored, since this factor has already been taken into account in calculating regional facility schedules.

inputs are the annual schedules of required energy supply facility additions in each of the 14 regions, calculated by the Regional Energy Facilities Generator, and the schedules of required energy transportation facility additions in each of the 14 regions, calculated by the Interregional Transportation Facilities Generator.

OPERATIONS RESOURCE REQUIREMENTS GENERATORS

The Operations Resource Requirements Generators specify the requirements of manpower, materials, and equipment (55 categories) for the normal operation and maintenance of each energy supply and transportation facility and for the whole energy system for each of the 14 model regions annually in the years 1974 through 1985. The logic is identical to that described earlier for the national model methodology in Section 3. Major inputs are the schedules of required energy supply facility on-line totals in the 14 model regions, calculated by the Regional Energy Facilities Generator, and the schedules of required energy transportation facility on-line totals by region, calculated by the Interregional Transportation Facilities Generator.

Section 5

USER ACCESS TO DECISION VARIABLES

Sections 3 and 4 describe in detail the methodological basis for the national and regional models. To facilitate use of the Energy Supply Planning Model, this section describes the major means by which the user interacts with the model. These means are referred to as "user interfaces." Particular emphasis is placed on the various user options available with each interface.

INTRODUCTION

The Energy Supply Planning Model is designed so that it is transparent to model users. To accomplish this, user access to the decision variables within each of the submodels has been deliberately emphasized. The interested user can control the behavior of the model through a step-by-step specification of decision variables, and, in so doing, can test the sensitivity of results to these variables.

In addition, an important factor in the design of user interface systems is to allow the user to specify variables at several levels of detail. This feature is intended to provide a hierarchy of significance that will be useful to energy policy makers and policy analysts alike. Thus, users may provide inputs at various levels of detail and obtain results at corresponding levels of resolution.

To allow this flexibility, reference (or, as they are sometimes referred to, default) specifications exist in the model for each of the user input

variables. Reference specifications are picked up by the model only when the user chooses not to exercise his prerogative to specify decision variables at any level of detail. No additional significance should be attached to these default values. The effort devoted to their development was, by intent, minor.

Table 2-4 (duplicated here) indicates the types of user input variables necessary to execute the various model options.

Table 2-4

**INPUT AND OUTPUT STRUCTURE FOR
REGIONAL FACILITY OUTPUT OPTIONS**

User Specified Input Variables	Output Options		
	National Facilities	Regional Energy Facilities	Regional Energy and Transportation Facilities
Future fuel mix	X	X	X
Energy facility location coefficients		X	X
Regional demand coefficients			X
Interregional fuel flow rules			X
Interregional transportation modal split coefficients			X

As can be seen, national analysis of all facilities requires the user to specify only the future fuel mix. For a regional analysis of energy supply facilities, input variables for the energy facility location coefficients must be specified as well. For a regional analysis of energy transportation facilities, all user input variables must be specified.

The user interfaces for these five types of input variables are described in this section with the intent of informing the user of the types of information required for a model run. Development of the reference (default)

data, including a description of the process by which default input variables were arrived at, is described in Appendix C.

FUEL MIX

The user interface for the Fuel Mix Generator consists of specifying the overview, primary, and secondary variables. The user may specify one or more (up to five) sets of values of the variables, typically for the years 1977, 1980, 1985, and 1990. For example, a national fuel mix can be analyzed at an aggregated level by specifying only the overview variables for the year 1985. The 1973 values for the variables are programmed on the basis of actual consumption data, released by the Department of Interior on April 3, 1975. Reference data are used as default values for those secondary variables not specified by the user.

User Input Options

Overview Variables. Table 5-1 lists overview variables along with instructions on how to specify them. Overview variables are specified within the context of total U.S. energy requirements. Thus, while only one column entry (usually conventional units) is required for input of overview variables to the Fuel Mix Generator, the user is requested to provide a second entry in Btu units. This mechanism is intended to ensure that the user considers the implications of his fuel mix in terms of total U.S. energy requirements.

The user may use conversion factors in Column 2 to convert his conventional unit inputs to Btu units. Conventional conversion factors have been used for most input variables. These are internal model parameters, not easy for the user to modify except through the services of a computer programmer. The one exception is in the electric

Table 5-1

OVERVIEW OF U.S. ENERGY REQUIREMENTS FOR (YEAR)⁽¹⁾

Fuel	1	2	3 = 1 + 2	4 = 3
Fuels for Electric Power	GWe	$\frac{10^{15} \text{ Btu/Y}}{\text{GWe}}$	10^{15} Btu/Y	10^{15} Btu/Y
1. Coal (enter in Columns 1 and 3)		.0865 x CF		
2. Heavy fuel oil (enter in Columns 1 and 3)		.0865 x CF		
3. Natural gas - high-Btu (enter in Columns 1 and 3)		.0865 x CF		
4. Low-Btu gas (enter Columns 1 and 3)		.0865 x CF		
5. Hydro (enter in Columns 1, 3, and 4)		.04726		
6. Nuclear (enter in Columns 1, 3, and 4)		.093 x CF		
7. Geothermal (enter in Columns 1, 3, and 4)		.162		
8. Pumped storage (enter in Columns 1, 3, and 4)		.0077		
9. Gas-turbine (enter in Columns 1, 3, and 4)		.118 x CF		
10. Combined-cycle (enter in Columns 1, 3, and 4)		.0747 x CF		
11. Fuel cells (enter in Columns 1, 3, and 4)		.0815 x CF		
12. Solid waste (enter in Columns 1, 3, and 4)		.0865 x CF		
Oil	MMEPD	$\frac{10^{15} \text{ Btu/Y}}{\text{MMEPD}}$	10^{15} Btu/Y	10^{15} Btu/Y
13. Motor gasoline (enter in Columns 1 and 3)		1.92		
14. Jet fuel (enter in Columns 1 and 3)		2.01		
15. Distillate oil other than electric power (enter in Columns 1 and 3)		2.13		
16. Heavy fuel oil, other than electric power (enter in Columns 1 and 3)		2.3		
17. Heavy fuel oil for electric power (enter in Column 3 the entry from Row 2, Column 3)		2.3		
18. Other light petroleum products (enter in Columns 1 and 3)		1.9		
19. All other petroleum products (enter in Columns 1 and 3)		1.49		
Total Petroleum Products Requirements (sum the entries in Column 3 of Rows 13 to 19; enter the sum in Column 4)				
Natural and Pipeline Gas	TCF/Y	$\frac{10^{15} \text{ Btu/Y}}{\text{TCF/Y}}$	10^{15} Btu/Y	10^{15} Btu/Y
20. Natural and pipeline gas other than for electric power (enter in Columns 1 and 3)		1,000.0		
21. Natural gas for electric power (enter in Column 3 the entry from Row 3, Column 3)		1,000.0		
Total Natural and Pipeline Gas Requirements (sum the entries in Column 3 of Rows 20 and 21; enter the sum in Column 4)				

(1) Either one or more future estimates may be provided.

Table 5-1 (Continued)

Low-Btu Gas	10^{12} Btu/Y	$\frac{10^{12} \text{ Btu/Y}}{10^{15} \text{ Btu}}$	10^{15} Btu	10^{15} Btu
22. Total low-Btu gas (enter in Columns 1, 3, and 4)		.001		
Coal	10^{15} Btu/Y	-	10^{15} Btu/Y	10^{15} Btu/Y
23. Coal, other than for electric power and synthetic fuels but including exports (enter in Column 3)				
24. Coal for electric power (enter in Column 3 the entry in Row 1, Column 3)				
Total Coal Requirements (sum the entries in Column 3 of Rows 23 and 24; enter the sum in Column 4)				
Methanol	MMT/D	$\frac{\text{Btu/Y}}{\text{MMT/D}}$	10^{15} Btu/Y	10^{15} Btu/Y
25. Total methanol (enter in Columns 1, 3, and 4)		$.6280 \times 10^{16}$		
Solar Heat	10^{15} Btu/Y	-	10^{15} Btu/Y	10^{15} Btu/Y
26. Solar space heating (enter in Column 3)				
27. Solar space conditioner (enter in Column 3 of Rows 26 and 27; enter the sum in Column 4)				
Total U.S. Energy Requirements (sum the entries in Column 4)	-	-	-	

generation sector where the capacity factors (CF) of the following power plants are an integral part of the fuel mix user specification:

- Coal-fired power plants
- Heavy-fuel-oil-fired power plants
- Natural-gas-fired power plants
- Low-Btu-gas-fired power plants
- Nuclear power plants
- Gas-turbine power plants
- Combined-cycle power plants
- Fuel cells
- Solid-waste-fired power plants

Primary Variables. The list of primary variables is shown in Table 5-2. As stated previously, the user is encouraged to specify primary variables for one or more future years.

Secondary Variables. The list of secondary variables is shown in Table 5-3. Most secondary variables are fractions, and, therefore, the appropriate quantities should sum to 1.0. One or more future estimates should be supplied, typically for years 1980 or 1985. For users who do not wish to specify the fuel mix at this final level of detail, reference (default) inputs are available. In addition, the user has certain options about how secondary variables are extrapolated for the 1985 to 1995 period. For 1990, the value may be given by the user, held constant, or extrapolated from the 1985 value (at the 1980 to 1985 growth rate). In all cases, fractions are held constant for the 1990 to 1995 period.

ENERGY FACILITY LOCATION COEFFICIENTS

The national model develops energy supply facility requirements at a national aggregation level. National requirements for adding new facilities are distributed regionally using the energy facility location coefficients that specify the fraction of national additions to be located in each of the model regions. Therefore, these coefficients directly determine the regional intensiveness of resources required to construct and operate energy supply facilities and, to a large degree, the derived transportation facilities requirements as well. For these reasons, the energy facility location coefficients represent the most significant regional interface to the Energy Supply Planning Model. Because of this, the user with regional interests is encouraged to specify the values of these coefficients. If he does not, the default values programmed into the model and described in Appendix C are used.

Table 5-2

PRIMARY VARIABLES

Variable	Requirement by Year				
	1973 ⁽¹⁾	1977 ⁽²⁾	1980 ⁽²⁾	1985 ⁽²⁾	1990 ⁽²⁾
OIL REQUIREMENTS (MMBPD)					
Crude storage (MMBPD)					
1. Amount of crude to be stored					
TOTAL CRUDE SOURCE DISTRIBUTION					
2. Fraction from foreign sources, etc.					
3. Fraction from conventional sources					
4. Fraction from oil shale					
5. Fraction from coal					
Total of Rows 2 to 4 must equal ⁽³⁾	1.0	1.0	1.0	1.0	1.0
IMPORTS OF REFINED PRODUCTS					
6. Fraction of heavy fuel oil from imports					
LOW- AND MEDIUM-BTU GAS REQUIREMENTS (TCF/Y)					
7. Low-Btu natural gas other than electric power					
SOURCES OF NATURAL GAS					
8. Fraction from imports					
9. Fraction from conventional sources					
10. Fraction as syngas from coal					
11. Fraction from coal mine degasification					
12. Fraction converted from heavy fuel oil					
13. Fraction converted from naphtha					
Total of rows 8 to 13 must equal ⁽³⁾	1.0	1.0	1.0	1.0	1.0
LIQUEFIED NATURAL GAS STORAGE (TCF/Y)					
14. Amount of natural gas to be stored					
OIL-FIRED PLANTS					
15. Fraction using oil					
16. Fraction converted to coal					
SOURCE DISTRIBUTION FOR OIL STORED					
17. Fraction from foreign sources					
18. Fraction from conventional sources					
19. Fraction from oil shale					
20. Fraction from coal					
Total of rows 17 to 20 must equal ⁽³⁾	1.0	1.0	1.0	1.0	1.0

Notes: (1) 1973 values are programmed based on actual data. Therefore, they need not be entered.

(2) Either one or more future estimates may be provided. The table shows typical years 1977, 1980, 1985, and 1990.

(3) The total must equal 1 if there is at least one positive entry in the column.

Table 5-3

SECONDARY VARIABLES

Variable	Requirement by Year		
	1973-75 ⁽¹⁾	1980	1985
OIL			
Crude -- conventional sources:			
1. Fraction from onshore wells, etc.			
2. Fraction from offshore wells			
3. Fraction from Alaska			
Total of Rows 1, 2, and 3 must equal ⁽²⁾	1.0	1.0	1.0
Sources of shale oil			
4. Fraction from mining complex			
5. Fraction from in-situ complex			
Total of Rows 4 and 5 must equal ⁽²⁾	1.0	1.0	1.0
Sources of imported crude			
6. Fraction from overseas, onshore facilities			
7. Fraction from overseas, offshore facilities			
8. Fraction from overland			
Total of Rows 6, 7, and 8 must equal ⁽²⁾	1.0	1.0	1.0
Sources of Alaska crude:			
9. Fraction from onshore, import facilities			
10. Fraction from offshore, import facilities			
Total of Rows 9 and 10 must equal ⁽²⁾	1.0	1.0	1.0
Imports of refined products			
11. Fraction of gasoline demand met from imports			
12. Fraction of distillate demand met from imports			
13. Fraction of other petroleum product demand met from imports			
Total of Rows 11, 12, and 13 must equal ⁽²⁾	1.0	1.0	1.0
COAL			
Sources of coal for direct use			
14. Fraction from underground Eastern mine			
15. Fraction from surface Eastern mine			
16. Fraction from underground Western mine			
17. Fraction from surface Western mine			
18. Fraction from imports			
Total must equal ⁽²⁾	1.0	1.0	1.0
NATURAL GAS			
Conventional sources:			
19. Fraction from onshore wells			
20. Fraction from offshore wells			
21. Fraction from Alaska			
Total must equal ⁽²⁾	1.0	1.0	1.0
Sources of imported natural gas:			
22. Imported overseas			
23. Imported overland			
Total must equal ⁽²⁾	1.0	1.0	1.0

Table 5-3 (Continued)

Variables	Requirement by Year		
	1973-75 ⁽¹⁾	1980	1985
METHANOL			
Sources of imported methanol			
24. Imported overseas			
25. Imported overland			
Total must equal ⁽²⁾	1.0	1.0	1.0
ELECTRIC POWER			
Coal-fired plants			
26. Fraction of plants using high-Btu coal			
27. Fraction of plants using low-Btu coal			
Total must equal ⁽²⁾	1.0	1.0	1.0
Coal sources for power plants using high-Btu coal			
28. Fraction from underground Eastern mine			
29. Fraction from surface Eastern mine			
30. Fraction from underground Western mine			
31. Fraction from imports			
Total must equal ⁽²⁾	1.0	1.0	1.0
Coal sources for power plants using low-Btu coal			
32. Fraction from surface Western mine			
33. Fraction from imports			
Total must equal ⁽²⁾	1.0	1.0	1.0
Fuel mix of coal-fired plants			
34. Fraction high-Btu coal			
35. Fraction solvent refined coal			
Total must equal ⁽²⁾	1.0	1.0	1.0
Sources of nuclear power			
36. Fraction from LWR without Pu recycle			
37. Fraction from LWR with Pu recycle			
38. Fraction from HTGR			
39. Fraction from FBR			
Total must equal ⁽²⁾	1.0	1.0	1.0
Sources of uranium			
40. From underground mine			
41. From surface mine			
42. From imports			
Total must equal ⁽²⁾	1.0	1.0	1.0
Fuel mix of oil-fired plants			
43. Fraction crude oil			
44. Fraction heavy fuel oil			
Total must equal ⁽²⁾	1.0	1.0	1.0
Fuel mix of oil-fired plants, converted to coal			
45. High-Btu coal			

Table 5-3 (Continued)

Variables	Requirement by Year		
	1973-75 ⁽¹⁾	1980	1985
Fuel mix of combined-cycle plants			
46. Fraction crude oil			
47. Fraction heavy fuel oil			
48. Fraction natural gas high-Btu			
49. Fraction natural gas low-Btu			
50. Fraction distillate oil			
Total must equal ⁽²⁾	1.0	1.0	1.0
Fuel mix of gas-turbine plants			
51. Fraction crude oil			
52. Fraction heavy fuel oil			
53. Fraction natural gas high-Btu			
54. Fraction distillate oil			
Total must equal ⁽²⁾	1.0	1.0	1.0
Distribution of coal/solid-waste-fired plants			
55. Fraction of plants using high-Btu coal			
56. Fraction of plants using low-Btu coal			
Total must equal ⁽²⁾			
Fuel mix of coal/solid-waste-fired plants			
57. Fraction coal			
Others			
58. Enriched uranium exports (metric ton/year)			
59. Fraction of total methanol as imports			
60. Electric power imports (GWe)			
Sulfur removal facilities			
61. Fraction from underground Eastern mine			
62. Fraction from surface Eastern mine			
63. Fraction from underground Western mine			
64. Fraction from surface Western mine			
Fuel mix of fuel cells			
65. Fraction natural gas, high-Btu			
66. Fraction distillate oil			
Total must equal ⁽²⁾	1.0	1.0	1.0
SYNTHETIC FUELS			
Coal sources for synthetic fuels			
67. Fraction from underground Eastern mine			
68. Fraction from surface Eastern mine			
69. Fraction from underground Western mine			
70. Fraction from surface Western mine			
71. Fraction from imports			
Total must equal ⁽²⁾	1.0	1.0	1.0
Output mix of coal liquifaction plant			
72. Fraction to coal liquid refinery			
73. Fraction as heavy fuel oil			
Total must equal ⁽²⁾	1.0	1.0	1.0

Notes: (1) 1973 values are programmed based on actual data. Therefore, they need not be entered.

(2) The total must equal 1 only if there is at least one positive entry in the column.

The user interface has been developed by grouping the 66 energy supply facilities into three categories of significance, based on whether the facility is judged to be:

- Most significant
- Significant
- Marginally significant

A facility is considered most significant if its location can significantly affect the total derived transportation facility requirements and/or total direct resource requirements of energy supply facilities at a regional level (for example, coal-fired power plants). A facility is considered marginally significant if its location seems likely to influence the total requirements of transportation facilities and resources only in a minor way. A facility is considered significant if it falls somewhere between the two extremes. This classification scheme is important because it allows the user the opportunity to derive reasonably accurate regional results by specifying energy facility location coefficients for only the 21 most significant facilities.

Tables 5-4, 5-5, and 5-6 show that each of the three groupings is subdivided into entries according to the major fuel types: oil, gas, coal, electric generation, and other (including nuclear fuel cycle and solar). Within each fuel group, facilities are further divided into three functions: those of resource exploration, recovery, and receiving; fuel conversion; and energy conversion.

User access to decision variables consists of specifying the entries in the tables. Each cell in the matrix has two entries. The upper or left diagonal entry shows the default value of the energy facility location coefficient available in the model. The user specifies his input entries

Table 5-4

MOST SIGNIFICANT ENERGY FACILITY LOCATION COEFFICIENTS

[illegible]

Table 5-4 (Continued)

Facility	Region													
	Northeast - 1	Mid-Atlantic - 2	South Atlantic - 3	East North Central - 4	East South Central - 5	West North Central - 6	West South Central - 7	Northern Mountain - 8	Southern Mountain - 9	Northern Pacific (including Alaska) - 10	Southern Pacific (including Hawaii) - 11	Atlantic Coastal - 12	Gulf Coastal - 13	Pacific Coastal - 14
COAL														
A. Resource Exploration, Development, Recovery, and Receiving														
1. Underground Eastern coal mine		1.4	3.8	39.0	58.0									
2. Surface Eastern coal mine		9.0	21.0	27.0	26.0	5.0	12.0							
3. Surface Western coal mine						32.0	88.0							
B. Fuel Conversion														
1. Coal gasification (high-Btu)		10.4	22.3	21.0	21.9	2.8	0.6	2.1	18.7	0.2				
2. Coal gasification (low- and medium-Btu)	1.0	18.0	13.9	3.1	11.0	12.4	25.1	0.6	2.0	1.6	5.3			
3. Coal liquefaction (heavy fuel oil)		10.3	22.3	21.0	22.0	2.8	0.6	2.1	18.7	0.2				
ELECTRIC POWER														
A. Resource Exploration, Development, Recovery, and Receiving														
None														
B. Energy Conversion														
1. Coal-fired power plant (low-Btu)				13.0		3.0		20.0	28.0	3.0	26.0			
2. Coal-fired power plant (high-Btu)	2.0	5.0	20.0	35.0	18.0		20.0							
3. Light water reactor	4.8	17.0	19.2	4.1	21.2	13.1	9.3	0.2	0.8	6.6	3.7			
4. Dam and hydroelectric power plant	7.0	4.0	3.0	7.0	6.0	1.0	1.0		2.0	39.0	30.0			
5. Pumped storage	7.0	4.0	3.0	7.0	6.0	1.0	1.0		2.0	39.0	30.0			

Table 5-4 (Continued)

Facility	Region													
	Northeast - 1	Mid-Atlantic - 2	South Atlantic - 3	East North Central - 4	East South Central - 5	West North Central - 6	West South Central - 7	Northern Mountain - 8	Southern Mountain - 9	Northern Pacific (including Alaska) - 10	Southern Pacific (including Hawaii) - 11	Atlantic Coastal - 12	Gulf Coastal - 13	Pacific Coastal - 14
OTHER FACILITIES, INCLUDING NUCLEAR FUEL CYCLE														
A. Resource Exploration, Development, Recovery, and Receiving														
None														
B. Fuel Conversion														
1. Uranium enrichment-diffusion			19.0	33.0	57.0									
2. Solar space heating					11.0		25.0		36.0		10.0			

Table 5-5

SIGNIFICANT ENERGY FACILITY LOCATION COEFFICIENTS

Facility	Region													
	Northeast - 1	Mid-Atlantic - 2	South Atlantic - 3	East North Central - 4	East South Central - 5	West North Central - 6	West South Central - 7	Northern Mountain - 8	Southern Mountain - 9	Northern Pacific (including Alaska) - 10	Southern Pacific (including Hawaii) - 11	Atlantic Coastal - 12	Gulf Coastal - 13	Pacific Coastal - 14
PETROLEUM														
A. Resource Exploration, Development, Recovery, and Receiving														
1. Crude oil stockpile							100.8							
B. Fuel Conversion														
None														
NATURAL GAS														
None														
COAL														
A. Resource Exploration, Development, Recovery, and Receiving														
1. Underground Western coal mine								100.8						
B. Fuel Conversion														
1. Coal gasification (methanol)		10.3	22.3	21.0	22.0	2.8	0.6	2.1	18.7	0.2				
2. Coal solvent refining	1.0	8.2	24.7	13.7	31.9		20.5							
3. Coal liquids refinery		8.6	1.4	9.4	2.1	2.5	38.0	1.3	1.7	4.0	31.0			

Table 5-5 (Continued)

Facility	Region													
	Northeast -1	Mid-Atlantic -2	South-Atlantic -3	East North Central -4	East South Central -5	West North Central -6	West South Central -7	Northern Mountain -8	Southern Mountain -9	Northern Pacific (including Alaska) -10	Southern Pacific (including Hawaii) -11	Atlantic Coastal -12	Gulf Coastal -13	Pacific Coastal -14
ELECTRIC POWER														
A. Resource Exploration, Development, Recovery, and Receiving														
None														
B. Energy Conversion														
1. Oil-fired power plant	10.0	18.0	16.1	3.1	11.0	12.4	25.1		2.0		5.3			
2. Sulfur oxide removal facilities		15.0	25.0	40.0	20.0									
3. High-Btu gas-fired power plants	0.3	3.6	8.5	6.9	3.5	10.7	46.7	0.2	5.3	0.2	14.1			
4. Gas-turbine power plants			24.0	24.0	24.0	3.0	15.0	1.0	2.0	1.0	6.0			
OTHER FACILITIES, INCLUDING NUCLEAR FUEL CYCLE														
1. Uranium mill							4.2	38.8	51.8	5.2				
2. Uranium conversion		20.0	20.0			30.0	30.0							
3. LWR fuel fabrication - no Pu recycle	20.0	10.0	20.0		10.0		10.0			10.0	20.0			
4. LWR fuel fabrication- Pu recycle		11.0	34.0		11.0		11.0			11.0	22.0			
5. LWR spent fuel reprocessing		16.0	34.0											
6. Solar space conditioning			19.0		11.0		25.0		35.0		10.0			

Table 5-6

MARGINALLY SIGNIFICANT ENERGY FACILITY LOCATION COEFFICIENTS

Facility	Region													
	Northeast - 1	Mid-Atlantic - 2	South Atlantic - 3	East North Central - 4	East South Central - 5	West North Central - 6	West South Central - 7	Northern Mountain - 8	Southern Mountain - 9	Northern Pacific (including Alaska) - 10	Southern Pacific (including Hawaii) - 11	Atlantic Coastal - 12	Gulf Coastal - 13	Pacific Coastal - 14
PETROLEUM														
A. Resource Exploration, Development, Recovery, and Receiving														
1. Oil shale mine ⁽¹⁾								10.0	90.0					
2. In-situ oil recovery ⁽¹⁾								10.0	90.0					
3. Alaskan oil export										100.0				
4. Offshore crude oil import												34.0	33.0	33.0
5. Onshore crude oil import	25.0	60.0	15.0											
B. Fuel Conversion														
1. Heavy fuel oil gasification		8.6	1.4	9.4	2.1	2.5	38.0	1.3	1.7	4.0	31.0			
2. Naphtha gasification		8.6	1.4	9.4	2.1	2.5	38.0	1.3	1.7	4.0	31.0			
3. Oil shale retorting and upgrading ⁽¹⁾								10.0	90.0					
4. Shale oil upgrading ⁽¹⁾								10.0	90.0					
NATURAL GAS														
A. Resource Exploration, Development, Recovery, and Receiving														
1. Coal mine degasification		13.4	34.1	13.4	19.0	0.1		1.0	18.9	0.1				
2. Alaskan LNG export										100.0				
3. LNG import.											100.0			
4. Natural gas stockpile	18.7	10.6	35.4	3.7	7.4	11.0	4.6	0.6	4.6	3.8				

Table 5-6 (Continued)

Facility	Region													
	Northeast - 1	Mid-Atlantic - 2	South Atlantic - 3	East North Central - 4	East South Central - 5	West North Central - 6	West South Central - 7	Northern Mountain - 8	Southern Mountain - 9	Northern Pacific (including Alaska) - 10	Southern Pacific (including Hawaii) - 11	Atlantic Coastal - 12	Gulf Coastal - 13	Pacific Coastal - 14
COAL														
None														
ELECTRIC POWER														
A. Resource Recovery and Processing														
1. Solid waste collection and separation plant	0.9	7.7	23.4	13.0	30.3	1.3	19.7	0.5	1.2	0.4	1.6			
B. Energy Conversion														
1. Reconversion of oil-fired power plants to high-Btu coal	20.0	35.0	35.0	10.0										
2. Coal/solid-waste-fired power plant (low-Btu)						25.2		10.4	24.0	7.2	33.2			
3. Coal/solid-waste-fired power plant (high-Btu)	1.0	8.2	24.7	13.7	31.9		20.5							
4. Low- and intermediate-Btu gas-fired power plant	0.6	6.3	18.4	10.5	23.8	6.3	15.8	2.6	0.6	1.8	8.2			
5. Combined-cycle power plant	10.0	15.0	13.9	3.1	11.0	12.4	25.1	0.6	2.0	1.6	5.3			
6. Fuel cells	10.0	15.0	13.9	3.1	11.0	12.4	25.1	0.6	2.0	1.6	5.3			
7. High temperature gas cooled reactor (HTGR)	4.8	17.0	19.2	4.1	21.2	13.1	9.3	0.2	0.8	6.6	3.7			
8. Fast breeder reactor (LMFBR)	5.5	11.2	14.9	2.9	22.4	11.1	15.5	0.7	1.3	6.6	7.9			
9. Geothermal power complex								20.0	20.0	10.0	50.0			

in the lower or right diagonal. Any or all rows of Tables 5-4, 5-5, and 5-6 may be specified in this way. User-specified rows are in all cases used in lieu of the default values for that row.

The user specifies entries for a given row (facility type) by answering the following question: "If you have to locate 100 additional facilities of the type indicated in this row, how would you distribute them over the 14 model regions?"* The entries for the 14 regions are then specified so that they sum to 100.

Thus, for example, Row 2 of Table 5-4 shows that reference data will cause the model to distribute 100 new offshore oil production facilities (lower 48) in the following manner:

- 25 in the Atlantic Coastal region (12)
- 25 in the Gulf Coastal region (13)
- 50 in the Pacific Coastal region (14)
- 0 in all other regions

The model formulation permits the external specification of time-dependent energy facility location coefficients to allow for changing facility location decisions over time. If only one set of entries per facility is provided, it is assumed to specify new facility locations for the entire model planning horizon, 1974 to 1995. If the user wishes to enter time-dependent location specifications for any facility, he merely enters a separate set of entries for each time period over which the entries are valid. In the above example, the user may wish to state that all new offshore oil production facilities until 1980 will be located in the Gulf Coastal region and that the above distribution then holds for additions in the 1981 to 1995 period.

* The number 100 is a normalization convenience; inputs are converted to fractions of new facilities (however many) added to those existing in 1973 to be located in the 14 regions.

In summary, the user specifies the energy facility location coefficients as follows:

- Identify the facility of interest
- Locate this facility in Tables 5-4, 5-5, or 5-6
- Specify the 14 regional entries by answering the question posed above. Provide additional sets of entries and the years through which they are valid if time-dependence is desired.
- Repeat these steps until the entries for all facilities of interest to the user have been specified

REGIONAL DEMAND COEFFICIENTS

As described in Section 4 of this report, the regional facilities-to-fuels transformer of the Interregional Fuel-Flow Generator determines regional supplies and demands for fuels, based on the locations of energy supply facilities and on regional demands for final fuels. The user, at his option, may specify the regional demands for final fuels through specification of the regional demand coefficients — the fraction of total national demand for fuels of the various types in each of the 11 land regions.

One user-specified regional distribution of national total demands is allowed over the model planning horizon. A user interface form for specification of the regional demand coefficients is presented in Table 5-7. Reference (default) values are included in the table for user convenience. The derivation of the reference (default) values is described in Appendix C of Volume II.

Table 5-7

USER INTERFACE FORM FOR REGIONAL DEMAND COEFFICIENTS

Fuel	Region										
	Northeast-1	Mid-Atlantic-2	South Atlantic-3	East North Central-4	East South Central-5	West North Central-6	West South Central-7	Northern Mountain-8	Southern Mountain-9	Northern Pacific (including Alaska)-10	Southern Pacific (including Hawaii)-11
Motor gasoline	5.1	14.6	15.4	19.2	6.4	9.6	11.4	1.2	3.9	2.9	10.3
Distillates	7.2	21.6	19.2	18.2	5.5	7.6	8.0	1.0	3.2	1.9	6.6
Other products	3.5	10.4	9.3	13.9	11.3	5.8	28.0	0.8	4.7	2.7	9.6
Methanol	5.1	14.6	15.4	19.2	6.4	9.6	11.4	1.2	3.9	2.9	10.3
Heavy fuel oil	11.1	33.4	29.7	5.2	1.7	2.2	2.8	0.4	2.0	2.5	9.0
Electricity	4.0	12.2	18.0	19.8	7.4	8.0	11.8	1.4	3.9	4.6	8.9
Coal (high-Btu)	0.1	17.4	26.8	38.7	7.7	3.1	2.1	0.4	2.2	0.3	1.2
Coal (low-Btu)	0	0	0	0	0	0	0	9.8	53.6	7.3	29.3
Natural gas	1.6	10.7	7.5	23.9	5.8	9.3	25.3	1.3	4.1	1.3	9.2

Note: (1) The coefficients are expressed as percentages; therefore every row must add to 100.

INTERREGIONAL FUEL FLOW RULES

The interregional fuel flow allocator determines the interregional fuel flow network, that is, the flow of fuels from regional supply centers to regional demand centers based on the regional supplies and demands for fuels and on user-specified regional fuel flow rules. Through specification of these rules, the model can generate a wide range of future flow patterns. The user may specify these rules or default to rules developed by the study team and described in Appendix C of Volume II.

The interregional fuel flow rules consist of specifying priority supply regions for each of the 11 demand regions as well as fuel allocation control variables that restrain the amount of a fuel allocated when a supply source is tapped. The model selects supply regions for meeting demands based on the priority supply set designations and allocates quantities of fuel based on the control variables.

A sample user interface form for specifying priority supply regions (in this case, for coal) is shown in Table 5-8.

Identical input tables have been provided for each fuel type (crude oil, refined products, heavy fuel oil, electricity, coal, and natural gas). In these tables, there are two priority supply sets: most-favorable supply regions and less-favorable supply regions. Least-favorable supply regions (those not included in either priority supply region) are tapped only if unsatisfied demand remains when all priority regions have been exhausted. Intraregional supplies are tapped before any priority supply sets are employed.

Table 5-8

**SAMPLE OF USER SPECIFICATION
OF PRIORITY SUPPLY REGIONS**

FUEL TYPE: COAL

Demand Region	Priority Supply Sets ⁽¹⁾	
	Most-Favorable Supply Regions	Less-Favorable Supply Regions
1	2	3
2	2,5	2
3	2,5	4
4	2,3,5,8	1,6,7,9
5	3,4	—
6	4,8	3,5,7,9
7	6	5,9
8	8	9
9	9	8
10	8	9,10
11	9	8,10,11

Note: (1) At most, five regions may be included in each priority supply set. There are no restrictions on putting the same region in both sets, or even twice in the same set, to increase the number of times it is tapped as a supply source.

In addition, the user may, at his option, specify values for the three fuel allocation control variables which determine the following information for each fuel:

- The fraction of a region's demand that may be met from intraregional supplies
- The fraction of a region's supply that may be allocated to intraregional demands
- The fraction of a region's remaining supply that may be allocated to any interregion demand

Preliminary experience with using the interregional flow rules indicates that the heuristic model gives the user extensive flexibility in controlling the flows of fuels. Generally, if a user has a specific fuel flow pattern to be simulated, it has been found that the most effective way to develop the input fuel flow rules is in a semi-iterative mode. The user begins by specifying his first impression of priority supply regions, and the results are compared against the desired simulation. Usually at this first stage, a few undesired flows will appear. The user then adjusts the priority supply sets and/or the fuel flow allocation control variables until the desired result is obtained. Typically, the desired simulation is approximated in one to three iterations of this kind.

In working with the scheme in this way, several aspects of its use have become apparent. Some of these are as follows:

- There is a tendency at first to define too few members in the two priority supply sets, i.e., demand regions have too few options. This causes the routine to branch to the third priority set (all regions) early in the allocation process, and quantities of flows over unlikely or unexpected routes may result.
- Input of lower values of the control parameters (e.g. 0.5) generally causes a greater number of routes to be used. This occurs because no demand region can deplete a supply region before many other regions have had an opportunity to tap the same source.
- Defining high values of the control parameters (e.g. 1.0) makes the supply-demand relationships more rigid, and a few large flows usually result. This behavior is similar to a "first-come-first-served" allocation where the first demand region to tap a supply region may deplete it.

INTERREGIONAL TRANSPORTATION MODAL-SPLIT COEFFICIENTS

As described in Section 4, the Interregional Transportation Facilities Generator converts interregional fuel flow networks to transportation

facility requirements, based on a great deal of detailed transportation system data (haul lengths, regional shares, carrying capacities, etc.) and user-specified (or default) interregional transportation modal-split coefficients. The modal-split coefficients specify the fractions of a particular fuel's incremental flow (positive or negative) over a particular origin-destination combination that is to be assigned to the various competing transportation modes. This section describes the user interface for these input variables. The development of default values for transportation of the various fuels is discussed in Appendix C of Volume II.

The dimensionality of the modal-split inputs is quite large. Needed to run the model are modal-split coefficients for incremental flows of fuel between each origin-destination pair to be considered (maximum of 165) for each fuel type for each mode (approximately 3 per fuel) for both positive and negative incremental flows. Since these amount to approximately 14,000 such coefficients, it is clear that few users will find it significant to specify all the input variables at this level of detail. Two methods are provided for user access to these modal splits. The first is for the user interested in detailed facility requirements between origin-destination pairs, and the second is for the user interested in more general transportation facility results.

The user has the option of specifying any or all of the detailed input values. For example, the user may choose only to specify the modal split for the transportation of crude oil between the West South Central region (Texas) and the Mid-Atlantic region (New York). It is estimated that significant flows of fuel between regions typically number on the order of 100; hence, a user can exercise a great deal of control over transportation facility results through the input of about 100 incremental modal-splits at this greatest level of detail (see Volume II, Section 11).

For a lesser detailed analysis, the user may wish to input transportation modal-split decision variables at a higher level of abstraction. An interface to the detailed default values has been designed that substitutes the origin of fuels rather than the interregional origin-destination combination as the basis for input specifications. For example, the user may specify that all coal originating in a particular region will be transported by unit train. This statement is then translated into the more detailed inputs for use by the model. The interface for this approach is described separately on the following pages for the transportation of fossil fuels and for the transmission of electricity.

Fossil Fuels

Table 5-9 is the complete user interface form for specifying interregional transportation modal-split coefficients for fossil fuels at this level of abstraction. The fuels include crude oil, refined products, heavy fuel oil, and coal. Natural gas is excluded because it is uni-modal (pipeline). Transportation of electricity is treated separately.

Each entry in the matrix specifies how a particular fuel is transported via a particular mode from a particular region. Thus, the matrix entry (1,1) specifies the fraction of crude oil originating in region 1 that is transported via pipeline. A total of 238 entries are required to specify the complete matrix.

The user specifies the entries in the matrix by answering the following question: "If you have 100 additional units (after 1973) of a particular fuel (crude oil, for example) to transport from a region, which mode(s) will you use and what portions of the 100 units of fuel will be carried by these modes?" The specifications entered in the matrix of Table 5-9 are then appropriately transformed for use in the model.

Table 5-9

USER INTERFACE FORM FOR FOSSIL FUEL MODAL-SPLIT COEFFICIENTS

[illegible]

In summary, the user specifies the modal-splits for crude oil, refined products, heavy fuel oil, and coal as follows:

- Select a region of interest
- Select a fuel of interest
- Specify the entries in the matrix of Table 5-9 by answering the question posed above
- Repeat the above steps until the entries for all regions and all fuels of interest to the user have been specified

Electricity

User input specifications for the calculation of electric transmission requirements differ for interregional vs intraregional flows of electricity. In the case of interregional transmission, the user (default) input consists of specification of "allowable" transmission modes for specific interregional links, modes which are then considered as candidates by the "least-cost" modal selection algorithm described in Section 4. To illustrate, a user can specify that the electric power from region 1 should be transmitted to region 2 by only 500-kV and 765-kV AC transmission lines. The heuristic algorithm described in Section 4 then assigns these modes to the transmitted electricity.

For intraregional transmission, however, the user may directly specify the amounts of electric power transmitted by the various modes within each region, in the same way as described above for fossil fuels. To specify intraregional modal splits, the user simply specifies the entries for regions of interest in the matrix shown in Table 5-10.

Table 5-10

**USER INTERFACE FORM FOR INTRAREGIONAL
ELECTRICAL TRANSMISSION MODAL SPLITS**

		230 kV	345 kV	500 kV	765 kV	400 kV DC
Regions						
1	Northeast					
2	Mid-Atlantic					
3	South Atlantic					
4	East North Central					
5	East South Central					
6	West North Central					
7	West South Central					
8	Northern Mountain					
9	Southern Mountain					
10	Northern Pacific					
11	Southern Pacific					

Section 6

FACILITIES DATA BASE

THE OBJECTIVES AND CRITERIA FOR DATA DEVELOPMENT

The model objective is to develop the capability for calculating the resource requirements necessary for the construction and operation of future exploratory configurations of the energy system. This requires, in turn, the development of data on those resource requirements for individual energy supply and energy transportation facilities. The development of these data constituted a significant study effort and resulted in the model data base.

Major resource categories included in the data base, as well as the level of disaggregation in each category, were selected by identifying those categories of requirements which would yield information significant to analyzing the feasibility of proposed future energy policy.

Resource requirements associated with the engineering and construction of facilities as well as with their normal operation and maintenance during their lifetimes were sought and included in the data base. These are referred to in the model as Construction Data and Operations Data, respectively.

Time was obviously a significant category; therefore, lead times for resources required for the engineering and construction of facilities, as well as the system lead time discussed in Sections 3 and 4 were included.

Capital resource requirements were developed in two-digit Bureau of Economic Analysis (U.S. Department of Commerce) categories to allow direct use in econometric and input-output models, that is, for planning at both the industry and the economy-wide levels, and to allow comparison with availability studies using this system of accounts. The categories are listed in Table D-1 in Volume II. It was also the explicit objective to make further adjustment to these categories as necessary for the direct use of the data in the somewhat modified BEA I-O table used at the Center for Advanced Computation (CAC) of the University of Illinois in Urbana.

The degree of disaggregation of data in the different categories was influenced by several considerations as described in the following paragraphs.

It was determined early that few current studies had input-output computation capability with tables much larger than the 1967 version, 87-order, BEA table. Thus, a cursory survey of potential usefulness, plus difficulties in developing capital categories in more detail for some of the newer technologies indicated that further disaggregation was not a realistic target for this study.

It was also considered significant to develop resource requirements data in selected categories of materials and equipment. The first was judged as significant in identifying possible constraints stemming from the shortages in basic materials supplies (e. g. reinforcing steel, cement); the other, in identifying possible constraints in production capacity for major equipment, i. e. to aid planning at the plant level. The latter led to the development of a list of selected major equipment for inclusion in the data base (e. g. turbogenerators). Both of these categories were combined, and information categories were developed for them in physical units (tons, item-years, 1,000 hp, and the like).

The resultant list of selected major materials and equipment was developed as a compromise between the desire to make the list as inclusive as possible and the need to have data in any one category available for most, if not all, facilities so that computed industry totals indeed be that. Generally, categories most commonly discussed as potential constraints were included. However, it is expected that information categories in this list will vary in significance depending upon the user's point of view.

Finally, manpower requirements were included in the data base. Selected categories of manpower were derived on the basis of their significance to the design, construction, and operation of energy facilities.

The final selection of the degree of disaggregation of data in any one category was made after most of the data had been accumulated and the availability of data in different categories ascertained.

RELATIONSHIP BETWEEN MODELING AND DATA DEVELOPMENT EFFORTS

Definition of the energy supply system, an early task in the development of the model, determines the number and kinds of energy facilities for which data need to be developed. The definition of facilities, in turn, has to be performed by the same people who can make statements about the appropriate nominal facility for the period of interest to be included in the definition of the system. This interdependence between the tasks resulted in a continuous flow of information and exchange, at the end of which 66 energy supply facilities and 25 energy transportation facilities were included in the energy supply system and the data base. Figure 6-1 is a pictorial description of information flow.

Figure 6-1. Facility Data Development and Processing Sequence

DIRECT AND INDIRECT RESOURCE REQUIREMENTS

In all cases, the direct resources required for the engineering, construction, and operation of the facilities were included in the model.

The term "direct" as used in this model refers to two specific qualities of the data:

- Only resources directly used in engineering and construction of energy facilities by establishments normally engaged in these activities, and resources directly used to operate energy facilities by establishments normally engaged in such activities were included. (In addition, so called "Owners Costs", described in earlier sections, are excluded as well.)
- More significant, perhaps, is the implication on the accounting scheme as it relates to the distinction between labor and capital direct requirements. This distinction may best be illustrated by the following example: In accounting for the resources needed to construct a coal-fired power plant, the boiler is a capital cost item, since a typical engineer constructor would normally purchase the boiler. Thus, all labor needed to manufacture and assemble the boiler parts are indirect and do not appear in the labor totals included in the resource requirements for coal-fired power plants.

USEFULNESS OF THE DATA BASE TO OTHER MODELS

In addition to serving the specific needs of the Energy Supply Planning Model for which it was designed, the data base developed during this study may be useful as a starting point for other efforts that use energy facility resource data. Preliminary experience, however, indicates that data needs of different modeling efforts require the development of specific data categories that may not have been developed as part of this study. A few examples may serve to illustrate this point.

Technology and Economics Optimization Models

If the primary purpose of a model is to optimize the technology to be used in a future energy system, data are required that state explicitly technology-cost relationships. This information, while extremely significant by itself, tends to be of secondary significance in relation to the purpose of the present study, since the emphasis is placed on obtaining information on the resources required, not on the technology best suited. (e. g. no distinction is made between a coal fired power plant using super-critical steam conditions and others; nor between BWR's and PWR's, etc.). Technology characteristics were significant for the purpose of this model only to the degree that the influence on resource requirements has been established as significant.

Net Energy Studies

If the purpose of a study is to determine the net energy available to the user of a given process, information is needed about categories of materials and equipment for which specific energy consumption data (e. g. Btu/lb, Btu/\$, etc.) have been developed or can easily be derived. Using the example of the coal-fired boiler, the information developed in this study (i. e. the boiler rating in Btu/hr and its total cost) may not be very useful for a net energy study. More useful data probably would have been provided by a disaggregation of boiler materials into components

for which specific energy consumption is known (e. g. Btu/lb of fabricated steel plate). As mentioned earlier in this section, information about resource requirements to construct a boiler are "indirect", and are excluded from the accounting scheme appropriate for the data base of this model.

ENERGY SUPPLY AND ENERGY TRANSPORTATION FACILITIES

The energy supply system consists of 66 facilities for energy exploration, development, production, processing, and conversion and of 25 facilities for transportation, transmission, and distribution of energy. These facilities are defined in Tables 6-1 and 6-2.

Each facility was nominally defined as that typical, in terms of its resource requirements, of one likely to be under construction during the period 1975 to 1985. This means that each definition reflects a level of technology expected to typify a plant being built during this period. The size and type-of-technology are assumed fixed during the time period.

The level of detail required for the definition of a nominal facility is determined primarily by three related factors:

- Definitional requirements to permit development of construction and operational data at an acceptable level of accuracy
- Availability of information on which to base a definition (especially for facilities dependent on newly developing technology)
- Design options considered likely

For this reason, the degree of detail used to define "nominal" facilities varies substantially. For example, to define a natural-gas-powered electric power plant, it is sufficient to state its heat rate and electric

Table 6-1

**DEFINITION OF ENERGY PRODUCTION AND
CONVERSION FACILITIES**

Name and Description	Input ⁽¹⁾	Output ⁽¹⁾
PETROLEUM		
<u>Exploration, Development, and Production</u>		
1. Onshore oil production (lower 48) — twenty 5,000-ft wells, gathering and production equipment, 15 dry holes	—	250 BPD crude 250 MCF/D gas
2. Offshore oil production (lower 48) — twenty-five 8,000-ft wells, platform and production equipment, one-mile pipeline to shore, 19 dry holes	—	4 MBPD crude 4 MMCF/D gas
3. Alaskan oil production — eighteen 9,900-ft wells and associated production facilities; 2 dry holes	—	180 MBPD
<u>Refining and Processing</u>		
4. High-gasoline refinery — major processes: distillation, Flexicoking, catalytic cracking, distillate hydrotreating, reforming, alkylation, and sulfur recovery	200 MBPD	Gasoline 61% of crude LSFO 0% of crude Other 36% of crude
5. Low-gasoline refinery — major processes: distillation, Flexicoking, distillate and gas oil hydrotreating, reforming, hydrogen production, and sulfur recovery	200 MBPD	Gasoline and naphtha 21% of crude LSFO 39% of crude Distillate 26% of crude
6. Heavy fuel oil gasification — major processes: partial oxidation, shift conversion, Rectisol absorption-regeneration, methanation, oxygen plant, and sulfur recovery	57.8 MBSD (5.6% S)	250 MMCF/D

Table 6-1 (Continued)

Name and Description	Input ⁽¹⁾	Output ⁽¹⁾
7. Naphtha gasification—principal processes: sulfur removal (ZnO bed), steam reforming, CRG (catalyst rich gas) methanation, CO ₂ removal (Benfield process)	35.3 MBPD	174 MMCF/D high-Btu
8. Crude oil stockpile—5 underground salt domes or caverns; 100 miles 32-in. oil line; 24-in. water pipes, pumps	50 MMB	48 MMB
9. Alaskan oil export—16 MMB storage, 5 berths for tankers up to 250,000 DWT	2 MMBPD crude	2 MMBPD crude
10. Offshore crude oil import—3 single point mooring buoys for 250,000 DWT tankers; two 12-mile, 48-in. pipelines; 12 MMB storage	1.7 MMBPD crude	1.7 MMBPD crude
11. Onshore oil import—7 MMB storage, marine terminal with 2 shore berths for tankers up to 90,000 DWT	1 MMBPD crude oil and refined products	1 MMBPD crude oil and refined products
OIL SHALE		
<u>Development and Production</u>		
12. Oil shale mine—room and pillar, 45-ft seam, 850-ft depth. Assumes ~65% recovery of the target 45-ft seam. Includes two 16%, 580-ft declines; two 3,000-ft drives; haulage and conveyor ways; buildings, utilities, and mining equipment	—	150,000 TPD oil shale
13. In-situ shale oil recovery—assumes 450-ft seam, 1,300-ft deep; cross-cuts, explosive fracturing to produce rubble; 5 miles of 4-in. (gas), and 6-in. (shale oil) pipelines to storage and processing; 50-day buffer storage	2	37 MBPD shale oil 33,000 TPD oil shale

Table 6-1 (Continued)

Name and Description	Input ⁽¹⁾	Output ⁽¹⁾
<u>Oil Shale Retorting and Upgrading</u>		
14. Oil shale sizing, 25 Petrosix type retorts, delayed coking, gas oil (1,600 psia) and naphtha (700 psia) hydrotreating, gas processing plant, hydrogen plant, ammonia recovery (Chevron WWT Process), and sulfur recovery (Claus and Wellman-Lord units)	165,000 STPSD raw oil shale	88,000 BPSD upgraded shale oil
15. Upgrading for in-situ shale oil - oil shale sizing and retorting of shale mined for underground retort; raw oil upgrading: delayed coking, hydrotreating, hydrogen production; NH ₃ and sulfur recovery	75.8 MBPD raw shale oil 67,900 TPD oil shale	90 MBPD upgraded shale oil
<u>NATURAL GAS</u>		
<u>Exploration, Development, and Production</u>		
16. Onshore gas production (lower 48) - ten 7,000-ft wells, gathering and production facilities, 8 dry holes	-	3 MMCF/D natural gas 50 BPD condensates
17. Offshore gas production (lower 48) - twenty-five 12,000-ft wells, gathering and production equipment, platform in 200-ft water, pipeline to shore, 19 dry holes	-	50 MMCF/D natural gas 2,000 BPD condensates
18. Alaskan gas production - twenty-four 9,900-ft wells, gathering and production facilities, 2 dry holes	-	250 MMCF/D natural gas 10.7 MBPD condensates
19. Methane from coal degasification - thirty 1,000-ft wells, gathering system, and compressor and metering station	-	1 MMCF/D methane

Table 6-1 (Continued)

Name and Description	Input ⁽¹⁾	Output ⁽¹⁾
<u>Other</u>		
20. Alaskan LNG export — marine terminal, fixed berths, 2 MMB storage, LNG plant with 8 trains (treating, dehydration, cascade liquefaction)	3,375 MMCF/D natural gas	3,030 MMCF/D equivalent LNG
21. LNG import — marine terminal, 2 docks, 2.2 MMB LNG storage, regasification, 38-mile 48-in. pipeline to transmission system	2,809 MMCF/D equivalent LNG	2,795 MMCF/D natural gas
22. Natural gas stockpile — includes drilling 50 production wells, high pressure large-diameter gathering system, processing plant (scrubber and dehydration), 6 x 8,000-hp compressor units, 30 miles of 30-in. connecting pipeline	Natural gas — 62×10^9 CF ⁽²⁾	60×10^9 CF natural gas
<u>COAL</u>		
<u>Development and Production</u>		
23. Underground Eastern coal mine — room and pillar, one 24-ft diameter concrete shaft, one 17° 14-ft x 14-ft x 2,900-ft stope; mining, onsite transportation, and processing equipment; assumes 5-ft seam, ~57% recovery	—	2MMT/Y coal
24. Surface Eastern coal mine — assumes level 6-ft seam, stripping ratio 16:1, ~90% recovery; includes initial stripping for 2 weeks production, mining, onsite transportation, and processing equipment	—	4MMT/Y coal

Table 6-1 (Continued)

Name and Description	Input ⁽¹⁾	Output ⁽¹⁾
25. Surface Western coal mine — assumes level terrain, 30-ft seam, 2.1:1 stripping ratio, ~90% recovery; includes initial stripping for 2 weeks production, mining, onsite transportation, and processing equipment	—	6MMT/Y coal
26. Underground Western coal mine — room and pillar, one 24-ft diameter concrete shaft, one 17° 14-ft x 41-ft x 2,900-ft stope; mining, onsite transportation, and processing equipment; assumes 5-ft seam, ~57% recovery	—	2MMT/Y coal
<u>Refining and Processing</u>		
27. Coal gasification (high-Btu) — Lurgi oxygen gasification, shift conversion, methanation, oxygen plant, sulfur recovery	27,500 TPD (8,300 Btu/lb)	250 MMCF/D
28. Coal gasification (low-Btu) — Lurgi air-blown system; gas treatment; Claus, Wellman-Lord sulfur recovery	27,500 TPD (8,300 Btu/lb)	282 × 10 ⁹ Btu/D
29. Coal gasification (methanol) — Koppers-Totzek oxygen-blown gasification; Imperial Chemical Industries methanol synthesis	36,400 TPD	15,100 TPD
30. Coal liquefaction (low-sulfur heavy fuel oil) — Synthoil process	10,000 TPD (11,000 Btu/lb)	24 MBPD
31. Coal solvent refining (SRC) — noncatalytic dissolver; amine gas purification; Claus, Wellman-Lord sulfur recovery	10,000 TPD (12,800 Btu/lb)	151.4 × 10 ⁹ Btu/D SRC 4.56 MTPD SRC 2.0 MBSD naphtha
32. Coal liquids refinery — includes Flexicoking, cat cracking, hydrotreating, reforming, alkylation, and sulfur recovery	100 MBPD	Gasoline 61% of feed LSFO 0% of feed Other 36% of feed

Table 6-1 (Continued)

Name and Description	Input ⁽¹⁾	Output ⁽¹⁾
NUCLEAR		
<u>Exploration, Development, and Production</u>		
33. Surface uranium mine — assumes level terrain, stripping ratio ~20 CY/ton ore, small ore body, ~80% recovery; includes exploratory survey, drilling, access roads; preproduction stripping (5×10^6 CY); diesel power plant, buildings, and mining equipment	—	1,200 T/D uranium ore
34. Underground uranium mine — includes exploratory survey, drilling, access roads; 16-ft x 500-ft shaft; 8 x 10-ft x 2,000-ft drifting; 8-ft x 10-ft x 2,000-ft crosscutting; 6-ft x 8-ft x 400-ft stope raises; buildings, power, and mining equipment; assumes "erratic" ore body, 80% recovery	—	500 T/D uranium ore
<u>Refining and Processing</u>		
35. Uranium mill — acid leach process	330,000 TPY uranium ore	880 TPY, 75% U_3O_8
36. Uranium conversion (U_3O_8 to UF_6) — acid dissolution, solvent extraction, calcination, hydrofluorination, and fluorination, product purification	10,000 MTU/Y yellowcake (75% U_3O_8)	9,990 MTU/Y uranium as UF_6
37. Uranium enrichment-diffusion — 8.75 million kg SWU	15,850 MTU/Y UF_6 (0.71% U^{235})	2,300 MTU/Y UF_6 (3.2% U^{235})
38. LWR fuel fabrication-no Pu recycle — oxidation of UF_6 to UO_2 , pelletizing, loading pellets into pins, and assembly into fuel elements	600 MTU/Y UF_6	600 MTU/Y fuel bundles

Table 6-1 (Continued)

Name and Description	Input ⁽¹⁾	Output ⁽¹⁾
39. LWR fuel fabrication-Pu recycle - oxidation of U and Pu compounds to oxides; pelletizing, loading into pins, fuel bundle assembly; includes glove-box handling of Pu	150 MTH/Y U and Pu compounds	150 MTH/Y fuel bundles
40. HTGR fuel fabrication - fertile particle production by Sol-gel process; includes calcination, coating, blending; preparation of fuel rods, loading into purchased graphite fuel elements; heat conditioning	MTTh/Y Th (NO ₃) ₄ ; 16 MTU/Y enriched UF ₆ (or Nitrate)	448 MTH/Y 24,000 fuel elements
41. FBR fuel fabrication - conversion of yellowcake to UO ₂ pellets; formation of PuO ₂ pellets, pellet blending, loading into pins, fuel bundle assembly; glove-box handling of Pu	290 MTU/Y U as UO ₂ or yellowcake 25 MTPu/Y Pu as PuO ₂	315 MTH/Y fuel bundles
42. LWR spent fuel reprocessing - cladding removal, Purex separation, U recovered as UF ₆ , Pu as PuO ₂ ; "disaster-proof" processing building; solidified waste	1,500 MTH/Y depleted fuel bundles	1,380 MTU/Y UF ₆ (enriched, depleted) 36 MTPu/Y PuO ₂ 80 MT/Y fission products
43. HTGR spent fuel reprocessing - processes: controlled burning, acid leach, solvent extraction	70 spent graphite blocks/day	283 MTTh/Y Th nitrate 11 MTU/Y U solutions 6 MTH/Y fission products
44. FBR spent fuel reprocessing - cladding removal; Purex separation, U and Pu to oxides, "disaster-proof" processing building, waste storage	950 MTH/Y depleted fuel bundles	800 MTU/Y 238 UO ₂ 90 MTPu/Y PuO ₂ 60 MT/Y fission products
45. High-level waste disposal - cannisters sealed in 2-in. C.S. casks, stored in outdoor concrete cylinders; receiving and handling capacity: 3,100 cannisters/Y	3,100 cannisters/Y	-

Table 6-1 (Continued)

Name and Description	Input ⁽¹⁾	Output ⁽¹⁾
ELECTRIC POWER-RELATED FACILITIES		
<u>Recovery and Processing</u>		
46. Solid Waste Collection and Separation Plant - includes dumping floor, air classification, magnetic metals separation, screening	500 TPD municipal waste	335 TPD combustible waste
<u>Electric Generation</u>		
47. Oil-fired power plant using crude oil or low-sulfur heavy fuel oil	9,875 Btu/kWh	800 MWe
48. Reconversion of oil-fired plant to high-Btu coal - assumes <6 months, \$2 MM conversion cost	9,875 Btu/kWh	250 MWe
49. Coal-fired power plant (low-Btu)	9,875 Btu/kWh	800 MWe
50. Coal-fired power plant (high-Btu) - also burns solvent refined coal	9,875 Btu/kWh	800 MWe
51. Coal/solid-waste-fired power plant (low-Btu coal) - 10% of Btu from waste	9,875 Btu/kWh	350 MWe
52. Coal/solid-waste-fired power plant (high-Btu coal) - 10% of Btu from waste	9,875 Btu/kWh	350 MWe
53. Sulfur oxide removal facility - regenerative sodium solution (Wellman-Lord) process with reduction to elemental sulfur	800 MWe plant stack gas	200 TPD sulfur
54. Low/intermediate-Btu gas-fired power plant	9,875 Btu/kWh	800 MWe
55. High-Btu gas-fired power plant	9,875 Btu/kWh	800 MWe
56. Combined-cycle power plant with gas turbine of 240 MWe; steam turbine of 160 MWe	8,530 Btu/kWh	400 MWe

Table 6-1 (Continued)

Name and Description	Input ⁽¹⁾	Output ⁽¹⁾
57. Gas turbine power plant	11,000 Btu/kWh	133 MWe
58. Fuel cell - fuel reformer (fuel oil, methane or naphtha), fuel cell, inverter, electrical equipment	9,300 Btu/kWh	26 MWe
59. Light water reactor (LWR)	-	1,100 MWe
60. High temperature gas-cooled reactor (HTGR)	-	1,500 MWe
61. Fast breeder reactor (LMFBR)	-	1,000 MWe
62. Dam and hydroelectric power plant	-	200 MWe
63. Pumped storage - 2 earth- filled dams, four 250-MW generating pumping units	-	1,000 MWe
64. Geothermal power complex - flash steam cycle, steam field development, 20% of drilled wells assumed dry	-	200 MWe
Other Facilities		
65. Solar space heating - 30,000 residential installations, each with 500-ft ² collector, 1,000- gal thermal storage, auxiliary boiler	-	2.1 x 10 ¹² Btu/season heating
66. Solar space conditioning - similar to above, plus 3-ton Li Br absorption chiller	-	2.1 x 10 ¹² Btu/season heating 0.8 x 10 ¹² Btu/season cooling
Notes: (1) <u>Abbreviations</u>		
B = barrel (oil)		
Btu = British thermal unit		
CF = standard cubic foot		
D = per day of operation		
kWh = kilowatt-hour		
lb = pound		
(continued)		

Table 6-1 (Continued)

Notes (Continued)

M = 1,000
MM = 1,000,000 } with barrels or cu ft only
MT = metric ton
MTH = metric tons of heavy metals (nuclear)
MTPu = metric tons as Plutonium
MTTh = metric tons as Thorium
MTU = metric tons as Uranium
MWe = metawatts, electrical
T = short ton
Y = per year

(2) 66×10^9 CF for first fill

Table 6-2

ENERGY TRANSPORTATION AND DISTRIBUTION FACILITIES

Name and Description	Input	Output
PETROLEUM		
1. Crude oil pipeline (lower 48) - 1,000 miles, 36-in. pipeline, 14 pump stations, 270,000 hp (inst.)	800 MBPD	800 MBPD
2. Alaskan oil pipeline - 800 mile, 48-in. pipeline, hotline operated, 50% above ground, 50% below ground, 10 miles refrigerated soil; 12 pump stations, 650,000 hp (inst.)	2,050 MBPD	2,000 MBPD
3. Products pipeline - 100 miles, 12-in. pipeline, 2 pump stations	70 MBPD	70 MBPD
4. Hot oil pipeline - 50 miles, 12-in. pipeline, polyurethane insulation, 1 pump station, 2 heating stations	40 MBPD crude or heavy fuel oil	39.8 MBPD
5. Oil tanker - 90,000 DWT, 24,500 shp, 17 knots, capacity 620 MB crude	620 MB/RT	620 MB/RT ⁽¹⁾
6. Oil barge - five 18 MB barges, one 3,000 hp tug, 9 knots	90 MB/RT	90 MB/RT ⁽²⁾
7. Oil tank truck - 300 hp tractor, 9,500 gal A1 tank trailer	9,500 gal	9,500 gal ⁽³⁾
8. Refined products bulk station - 500 MB storage capacity, manifolds, loading pumps, 12 double loading racks, metering, and controls	50 MBPD (approx.)	50 MBPD (approx.)
COAL		
9. Coal train (excluding roadbed) - 105 operating 100-ton hopper cars, 10 spare cars, four 3,000 hp locomotives, 8% spares	10,500 tons/trainload	10,500 tons/trainload

Table 6-2 (Continued)

Name and Description	Input	Output
10. Coal slurry pipeline (excludes coal preparation and dewatering) - 1,000 miles, 38-in. diameter; 10 pump stations; 140,000 hp (inst.), water and slurry ponds, re-mix tank, water well	140 MTD coal slurry	140 MTD coal slurry
11. Coal slurry preparation - five 5 MM ton preparation plants; agitated slurry storage, water supply, and storage system	70 MSTD coal 18×10^6 gal water	140 MSTD slurry
12. Coal slurry dewatering - slurry tanks, dewatering, and water treatment plant	140,000 STD	68,600 ST/D fine coal 15×10^6 GPD water
13. Coal barge - fifteen 1,400 ST hopper barges, one 4,200 hp tug	21,000 ST per trip	21,000 ST per trip
14. Coal truck - on highway, 12-1/2-ton semi 12-1/2-ton trailers, empty weight, 15T	25 tons coal per trip	25 tons coal per trip
NATURAL GAS		
15. Gas pipeline (lower 48) - 1,000 miles, 36-in. pipeline, 13 compressor stations, 252,000 hp (inst.)	870 MMSCF/D	830 MMSCF/D
16. Alaskan gas pipeline - 809-mile, 42-in. chilled pipeline, 12 compressor stations, 562,000 hp (inst.); 11 refrigerating plants, 4 maintenance bases	3,500 MMSCF/D	3,375 MMSCF/D
17. LNG tanker - capacity $125,000 \text{ m}^3$, 785 MB, 2.6×10^9 SCF, 5 spherical Al tanks, speed 20 knots	2.6×10^9 SCF/RT	2.6×10^9 SCF/RT ⁽⁴⁾

Table 6-2 (Continued)

Name and Description	Input	Output
18. Gas distribution facilities - includes main station, 4 sub-stations, metering and control equipment, city mains, secondary lines, and connection to meters for 24 mi ² urban area of 100,000 population	50 MMSCF/D	50 MMSCF/D
19. Rail line (excludes rolling stock) - 40 miles of single track, ballasted, with 119 lb/yd rail and no significant structures	See coal train	See coal train
20. Overhead transmission line (230 kV AC) - 500 miles of 230 kV AC transmission line 3-phase, cable is 1-1,590 ACSR	600 MVA at 230 kV 3Ø Ac	Input minus 34%
21. Overhead transmission line (345 kV AC) - 500 miles of 345 kV AC transmission line, 3-phase, cable is 2-954 ACSR	1,200 MVA at 345 kV 3Ø Ac	Input minus 18%
22. Overhead transmission line (500 kV AC) - 500 miles of 500 kV AC line, 3-phase, cable is 2-2,156 ACSR, 500/230 kV station	2,600 MVA at 500 kV 3Ø Ac <i>phase</i>	Input minus 11%, 230 kV <i>loses 2% compounded per 100 miles</i>
23. Overhead transmission line (765 kV AC) - 500 miles of 765 kV AC line, 3-phase, cable is 4-959 ACSR, 765/230 kV station	4,000 MVA at 765 kV 3Ø Ac	Input minus 7%, 230 kV
24. Overhead transmission (400 kV DC) - 800 miles of 400 kV DC, cable is 2-2,300 ACSR rectifier and inverter	1,430 MVA at 13.8 kV Ac	Input minus 8%, 230 kV Ac

*at nominal
65% load
6833 billion
KWH/yr*

*transformer loses 2% of
what it gets*

Table 6-2 (Continued)

Name and Description	Input	Output
25. Electric distribution facilities - 36 circuit miles aerial, 18 circuit miles underground, drops for 100 industrial (500 kW each), 2,400 commercial (14 kW each), and 18,300 residential (2 kW each) customers	143 MV at 230 kV	70.2 MW, 1Ø-220 V AC 21 MW, 3Ø-13.2 kV AC 29 MW, 3Ø-34.5 kV AC

NOTES:

- (1) Add 5 days per round trip for port and lost time
- (2) Add 3 days for port and list time
- (3) Average 200-mile round trip per operating day

power output. Such plants are based on well established and well known technology and have relatively few design options to vary from a nominal case that are likely to influence construction and operation resource requirements within the limits of acceptable data accuracy.

On the other hand, a facility such as a coal gasification plant is less well known and has several possible design options. The process used must be specified to establish construction and operation requirements.

Employing the nominal facility concept in modeling can produce useful results, but chances for error are inherent and should be recognized. For example, estimates of energy-related resources requirements will err to the extent that the nominal facility selected differs from those that actually are built and operated during the study time frame. As an illustration, the sulfur oxide removal (from plant exhaust gases) facility for the model is nominally defined as based on the Wellman-Lord sodium solution process. Other processes - based on lime, magnesia, etc. - may be built and make the model estimates for requirements for certain items (e.g. sodium hydroxide) high and

others (e. g. lime and effluents to be disposed of) low. Estimates for process equipment and construction materials would also probably err though less significantly. Major parameter specifications for each of the 91 energy system facilities are summarized in Tables 6-1 and 6-2.

CONSTRUCTION RESOURCE DATA

This section presents a description of construction resource data developed for the model data base including data development procedures, data classification, and data quality. The complete construction resources data base is contained in the magnetic tape accompanying this report.

Definitions and Assumptions

The major items of construction resource data are direct requirements of capital, manpower, materials, and equipment. The scope, degree of disaggregation, and classification of these data reflect the perspective of the constructor, i. e., a firm in the construction industry.

Construction resources data include all resources that are the responsibility of the construction firm from contract award or approval to end of facility startup. This includes resources required for engineering, design, procurement, construction, and startup for each energy facility. By this definition, other costs normally borne by the owner of the facility are excluded. These "owner's costs" include:

- Project feasibility studies
- Site evaluation
- Studies required for site and project government agency approval (including environmental impact studies)
- Interest during construction

- Inventories and working capital
- Royalties
- Cost of community facilities
- Land costs
- Other owner's costs

Owner's costs vary widely but average 25 to 30 percent of construction costs incurred by the builders for many major energy facilities. They are higher for energy extraction facilities, of the order of 40 to 60 percent. Rough estimates of owner's costs are listed in Table D-2 in Volume II.

In addition to defining the scope of construction data, the constructor perspective also influences the level of disaggregation of data. For energy facilities normally built by an engineering construction firm, such as a power plant or natural gas pipeline, fully detailed data were developed showing each major item of capital, manpower, material, and equipment required. However, for certain items normally manufactured in other BEA sectors and purchased by an A&E, only capital cost data were estimated. This applies to mobile transportation facilities, such as an oil truck or train, as indicated below.

Resource Data	Mobile Transportation Facilities	All Other Facilities
Time		X
Capital	X	X
Manpower		X
Materials and Equipment		X

A nominal location and technology typical of the 1974 to 1985 period are assumed. In all cases cost data are given in terms of third-quarter-1974 prices, f. o. b. construction site.

Data Sources and Procedures

Because of their background and experience in construction of energy related facilities, the Operating Divisions of Bechtel were requested to develop construction resource data. Responsibility for coordinating the data effort and for developing data for advanced technology facilities was centered in the study team.

Figure 6-2 shows a schematic of the construction data development process. Principal information sources were based on past construction experience, literature, and industry contacts. Where appropriate and where time permitted, process diagrams were prepared for developing equipment lists, labor requirements, and cost estimates. Capital construction cost estimates for mobile transportation facilities were obtained from vendors, builders, or manufacturers.

Data Accounting System

The construction data were organized and classified to emphasize the following factors:

- Major categories of resources important to construction
- Major individual construction items
- Resources potentially in short supply
- A system of totals and subtotals to permit systematic reporting at varying levels of aggregation
- The BEA system of accounting (for materials and equipment)
- Data availability

Figure 6-2. Construction Resource Data Development Process

Manpower Data. Classification of manpower requirements took into account the U. S. Department of Labor system and the categories normally employed by unions and industry. The categories commonly used by unions and industry were adopted. Table 6-3 lists the categories of manpower included in the model data base.

Materials and Equipment. The BEA system of accounting was used for capital categories of materials and equipment resource data as they pertain to industries. The miscellaneous category includes materials and equipment in all classifications not listed separately. With a few exceptions, miscellaneous totals amount to between one and five percent of total capital cost. The main industry categories are grouped as shown in Table 6-4.

Table 6-3

**MANPOWER RESOURCES REQUIRED FOR
CONSTRUCTION OF ENERGY FACILITIES**

(Man-Years)

Nonmanual	Manual
Technical Chemical engineers Civil engineers Electrical engineers Mechanical engineers Mining engineers Nuclear engineers Geological engineers Petroleum engineers Other engineers Total engineers Total designers & draftsmen Total supervisors & managers Total technical Nontechnical Total nontechnical	Craftsmen Pipefitter Pipefitter/welder Electrician Boilermaker Boilermaker/welder Iron worker Carpenter Operating engineer Other major skills Total major skills Other craftsmen Total craftsmen Teamsters and laborers Total teamsters and laborers

Table 6-4

**CAPITAL RESOURCES REQUIRED FOR
CONSTRUCTION OF ENERGY FACILITIES**

(Millions of Dollars, Third Quarter 1974)

Resource	BEA Category
Materials	
Wood products	20
Chemical and allied products	27, 28, 30, 32
Petroleum products	31
Stone and clay products	36
Primary iron and steel products	37
Primary nonferrous metals	38
Fabricated structural products	40
Other fabricated products	42
Materials subtotal	
Equipment	
HVAC heating and cooling units	52
HVAC ductwork and accessories	40
Turbines	43
Construction, mining, and oil field equipment	45
Gas welding sets and metal-working equipment	47
Electric welding sets	53
Materials handling equipment	46
General industry equipment	49
Instrumentation and controls	62
Electrical equipment	53
Fabricated plate products	40
Miscellaneous	1-68, except above
Equipment subtotal	
Construction capital cost total	

List of Major Items. As discussed earlier, two classes of planning objectives guided the design of the data effort: planning at the industry level, and planning at the plant capacity and basic materials level. The list of categories of selected major equipment and materials is given in table 6-5.

Lead Times

Construction resources are expended at various rates during the construction period. To account for this effect, it is necessary to develop not only the total resources of a given type expended during the construction period but also the percentage of the total resources that are required during each year of the construction project, as shown in Table 6-6. To accomplish this, time-phased data were developed for six different resource category groupings:

- Nonmanual, technical manpower
- Nonmanual, nontechnical manpower
- Craftsmen
- Teamsters and laborers
- Materials and equipment
- Capital expenditures

This grouping of individual items into groups introduces some distortions in the time-phasing of individual requirements (e.g. data on requirements for concrete and nuclear steam supply systems for nuclear power plant construction are time-phased in the same way, as are all materials and equipment). If greater accuracy in individual category results is desired coarse groupings could be further subdivided into subgroups of items with similar time-phasing characteristics by a simple model modification and associated data development.

Table 6-5

**SELECTED MAJOR MATERIALS AND EQUIPMENT RESOURCES
REQUIRED FOR CONSTRUCTION OF ENERGY FACILITIES**

Resource	Units
Refined products	Tons
Cement	Tons
Ready-mixed concrete	Tons
Pipe and tubing:	
Less than 24-in. dia.	Tons
24-in. dia. and greater	Tons
Oil country tubular goods	Tons
Steel forgings	Tons
Iron and steel castings	Tons
Structural steel	Tons
Rebar	Tons
Valves - 24-in. dia. and greater	Items
Valves - 24-in. dia. and greater	Tons
Steam turbogenerator sets	1,000 hp
Steam turbines without generators	1,000 hp
Gas turbogenerator sets	1,000 hp
Gas turbines without generators	1,000 hp
Draglines	Cubic Yards
Draglines	Tons
Drill rigs	Item-years
Pumps and drivers - greater than 100 hp	Items
Pumps and drivers - greater than 100 hp	Tons
Compressors and drivers - greater than 1,000 hp	Items
Compressors and drivers - greater than 1,000 hp	Tons
Heat exchangers	1,000 ft ² surface
Pressure vessels - greater than 1-1/2-in. plate	Tons
Boilers	Million Btu/hour
Nuclear steam supply systems	GWe

Table 6-6

TIME-PHASED CONSTRUCTION RESOURCE REQUIREMENTS

Year	1	2	3	4	5	6	7	8	9	10	TOTAL
Lapsed Time (Mos.)	—	—	—	—	—	—	—	—	—	—	—
	(% of Total)										
Nonmanual											
Technical	—	—	—	—	—	—	—	—	—	—	100
Nontechnical	—	—	—	—	—	—	—	—	—	—	100
Manual											
Craftsmen	—	—	—	—	—	—	—	—	—	—	100
Laborers and teamsters	—	—	—	—	—	—	—	—	—	—	100
Materials and Equipment	—	—	—	—	—	—	—	—	—	—	100
Capital Expenditures	—	—	—	—	—	—	—	—	—	—	100

Accuracy and Quality

Actual resources required to construct an energy facility may vary greatly from the corresponding estimate in the data base. These variances result, principally, from the following:

- Variations inherent in actual construction — soil, weather, materials availability, strikes, construction management practices, and regional factors (labor productivity and rates, shipping costs, climatic conditions). To reduce the impact of regional differences, some nominal facilities are defined by region, e.g., Eastern and Western coal mines, Alaskan and lower 48 oil production, etc.
- Amount of information available to the estimator — status of technology on which a plant is based, data base, construction experience. For example, data about in-situ shale oil production is untested and sketchy, while coal-fired power plants are based on proven technology with actual construction experience records available and correspondingly accurate data

Accuracy of the data collected was checked by:

- Comparison with applicable literature
- Review by independent estimators
- Review by industrial representatives
- Comparison for logic and consistency with data about similar facilities, e.g. electric power plant steam sections should be similar whether the plant uses high-Btu or low-Btu coal, and any differences should be logical and explicable
- Study of "crosscut" comparisons of normalized data for different facilities in search for errors. Table D-3 in Volume II shows this normalization for capital cost data in relation to energy output

As a result of the many variables influencing the estimating process, the uncertainty of resource data estimates vary widely. Some are characterized as "accurate;" others are only very rough approximations.

An effort was made to characterize uncertainty for each estimate. Values of the uncertainty of data accuracy are subjective and reflect the estimator's intuition.

Table 6-7 illustrates that, in general, accuracy estimates for facilities based on established technology, e.g. power plants, pipelines, etc., fall in the range of ± 10 to 20 percent. For facilities involving new or rapidly developing technology and for which limited data are available, estimate accuracy may range from -30 to +75 percent. Confidence in estimates normally decreases as the level of detail increases. The estimated accuracy of construction data for each facility is listed in Table D-4 in Volume II.

Table 6-7

**EXAMPLES OF ESTIMATED UNCERTAINTIES (SUBJECTIVE)
ASSOCIATED WITH FACILITY RESOURCES DATA**

Facility	Base Value	Percent Uncertainty	Resulting Range of Values
Construction of coal-fired power plant (800 MWe)			
• Capital cost (\$ million)	220	+20 -10	198 - 264
• Total engineers (1,000 man-hours)	409	+20 -10	368 - 491
Construction of in-situ shale oil recovery facility (37,000 BPD)			
• Capital cost (\$ million)	100	+60 -20	80 - 160
• Total engineers (1,000 man-hours)	350	+75 -30	245 - 612

Oil and Gas Exploration Development and Production (ED&P) Facilities

The oil and gas ED&P facility data are subject to yet another uncertainty that involves estimates of average future outputs from the nominal facilities. The procedures used for these estimates are similar to those used by the National Petroleum Council and the FEA Project Independence Blueprint (PIB) Oil and Gas Task Forces. Production rates are estimated by combining assumptions for: oil finding rates (including rates for exploratory footage and total footage drilled), dry hole ratios, factors for recovery of oil in place, and reserve withdrawal rates. Oil finding rates in particular have fluctuated widely,

e. g. from about 40 to 1,500 barrels per exploratory foot drilled in California and 40 to 350 barrels per foot in Texas. These and other uncertainties inherent in estimating future oil and gas production rates prompted the PIB Gas Task Force team to state "the conclusion to be drawn from these considerations is that the projections made here using the NPC methodology, while they represent our best educated effort at this time, are subject to serious error, and should be interpreted and used with extreme caution." (Federal Energy Administration, Project Independence Blueprint, Final Task Force Report, Natural Gas, November 1974.)

OPERATIONS RESOURCE DATA

The following paragraphs describe operations resource data developed for the model data base and examine data development procedures, data classification, and data quality. The complete operations resources data base is contained in the magnetic tape accompanying this report.

Definitions and Assumptions

The major categories of operations resource data are the direct manpower, materials, and equipment required to operate energy supply and energy transportation facilities. The scope, degree of disaggregation, and classification of these data reflect the perspectives of the establishments usually involved in operating such facilities.

It was the intent of data development and of the modeling effort to include environmental effluent data resulting from the operation of energy facilities, consumption of water, and the requirements for land resources (e. g. for the operation of surface coal mines).

The efforts made to obtain such data were only partially successful; work supported by Government agencies is currently underway to

estimate the character and quantity of effluents for a number of energy facilities. (However, data were obtained from Brookhaven National Laboratories for certain energy facilities using only conventional technology.) Since effluent data are significant and this task may be completed at a later date, the present computer program was developed to accommodate effluent information (see Volume II for computational scheme and reserved spaces for effluent data processing).

Scope and Assumptions

The principal focus of the operations data effort was on manpower, materials, and equipment required to operate energy facilities. Data were also obtained for the consumption of domestic energy resources (coal, gas, oil, shale and uranium) during the operation of resource extraction facilities. These data refer to extraction coefficient, allowing for computation of consumption of resources in place. Operating resources include the labor, materials, and equipment directly involved in plant operation; they exclude central management and staff activities.

The following are principal items excluded from operating resource requirements:

- Main office expense
- Sales and Clerical
- Corporate R&D
- Capital charges
- Taxes, royalties, and fees
- Insurance

The general guidelines for developing operations data were:

- Operations requirements to be representative of those of new nominal facilities identical to the nominal facilities defined for construction resources data

- Requirements to be expressed as average annual needs for direct operations including home office assistance and contract operations but excluding personnel, sales, accounting, and similar support functions
- For mature industries and facilities, conditions to be typical of advanced but already commercialized activities; industry changes assumed not to materially affect requirements
- Cost data to be expressed in fixed third-quarter-1974 dollars, identical to construction resources cost data
- Estimates of the accuracy of the data, as well as scaling factors and the associated ranges of facility sizes, to be supplied if such information were readily available
- The manpower, materials, and equipment cost data obtained during the study were not designed to establish the full operating cost for the energy-related facilities. Rather, the intent was to obtain data in sufficient detail to establish the industrially significant manpower, material, equipment, and utility quantities for each facility for the purpose of identifying potential bottlenecks.

Sources and Procedures

Bechtel sought the assistance of a research firm whose special skills uniquely qualify it to develop data on energy facilities operating requirements; proposals for this work were solicited from nine research firms. The Stanford Research Institute's (SRI) proposal was accepted. It covered development of operating data for 67 energy facilities.

SRI completed its operations data development in March 1975 and submitted its final report to Bechtel. This report, entitled "Manpower, Materials, Equipment, and Utilities Required to Operate and Maintain Energy Facilities," constitutes a principal source of information on which the operations data base draws.

Data for the remaining facilities, as well as adjustments of the SRI supplied data, were developed by the study team.

The approach to data development taken by the individual investigators was not identical because of the wide variety of facilities considered and variations in industry practice, degree of industrial development, and information sources available for each general area and specific facility. However, in each case the pattern was similar: extensive discussion and interchange took place between the several investigators and the project leader responsible for data development throughout the investigations to establish and maintain consistent sets of background data and interpretation for use in the analyses.

Sources of information on which operating data estimates were based include:

- Data from actual operating facilities if available within the time of performance and funding for the research; the data were modified by the best available engineering judgments to meet expected operational conditions for new facilities anticipated in the 1975 to 1985 period
- Extrapolation, interpolation, and other judgments in the absence of direct operational data
- Literature references
- Estimates based on recorded industry averages
- Operating data based on estimated plant capital costs

Data Accounting System

Materials and equipment data for normal operation and maintenance of energy facilities were also accumulated in the BEA system of accounts, but in major categories different from those used for construction data. The different categorization of operating data was selected primarily because of the differences in makeup between operating and maintenance data and construction data. Individual operating data categories and procedures for data development are discussed in the following paragraphs.

Manpower Data. Manpower estimates were based on normal requirements for operation of the facility. (Even though accounting, personnel, warehousing, and sales activities are essential to process facility performance, these requirements were excluded from consideration.)

Guard and materials control activities mandated or expected to be mandated by federal regulations for nuclear facilities were included as were home office or contract services generally used for direct operations, control, or maintenance. Manpower requirements were expressed in average man-years per year to account properly for contract maintenance and support services usually supplied intensively for short periods of time on an intermittent basis.

The distribution of manpower among the various specialties was based either on definitive data obtained from operators of facilities, on the accumulated experience of specialists analyzing each facility, or on industry averages such as those given in BLS and USAEC publications. Medical support personnel were assumed to be a necessary part of large-scale, onsite activities, and the nurses or paramedic personnel directly employed at the facility were included in the "Other Technical" personnel category. Scientific personnel such as chemists and physicists were also listed under "Other Technical." Physicians were not generally included. Table 6-8 lists operating manpower data categories.

Materials. Materials requirements were adopted from published requirements for similar facilities, from discussions with operators of similar industrial facilities, from SRI proprietary data, and from calculations based on plant process flow sheets. In some instances materials requirements were estimated from flow sheets for typical facilities, published data of the Federal Power Commission (FPC) or similar filings, annual reports to the FPC and Interstate Commerce Commission (ICC), or special articles describing individual processes. Emphasis

Table 6-8

OPERATING MANPOWER DATA CATEGORIES

Category	Man-Years
Technical	
Chemical Engineers	
Civil Engineers	
Electrical engineers	
Mechanical engineers	
Mining engineers	
Nuclear engineers	
Geological engineers	
Petroleum engineers	
Other engineers	
Total engineers	
Total designers and draftsmen	
Total supervisors and managers	
Other technical	
Total technical	
Nontechnical (nonmanual)	
Total nontechnical (nonmanual)	
Craftsmen	
Pipefitters	
Pipefitter/welders	
Electricians	
Boilermakers	
Boilermaker/welders	
Iron workers	
Carpenters	
Equipment operators	
Other operators	
Underground miners	
Welders - unclassified	
Other major skills	
Total major skills	
Other craftsmen	
Total craftsmen	
Teamsters and laborers	
Total teamsters and laborers	

was placed on materials essential to the operation of the facility. As appropriate, the data were adapted or scaled to fit the average or typical facility size selected.

Various sources were used for price information. Principal data were obtained from "Current Prices of Chemicals and Related Materials,"* from direct quotations by chemical or materials vendors, or by the individual investigators from appropriate sources. When prices or costs were extrapolated from earlier quotations, the Chemical Engineering (CE) Cost Index** was used to represent price changes or inflation. A CE Index of 168 was used to represent costs.

Emphasis was placed on materials essential to facility operation or consumed in significant quantity; other materials received less attention. This procedure emphasizes the essential and significant (from a production or supply standpoint) materials, but understates the dollar value of supporting materials and supplies. Therefore, some dollar expenditures recorded for materials and equipment may understate slightly the non-labor, operating and maintenance costs. In instances where only the total material costs were available, the analyst distributed costs to general Standard Industrial Classification or Bureau of Economic Analysis codes on the basis of general industry averages or his best judgment.

Categories selected for reporting energy facility operating materials and equipment are shown in Table 6-9.

* Chemical Marketing Reporter, Schnell Publishing Co., Inc., 100 Church Street, New York.

** Chemical Engineering, published biweekly by McGraw-Hill, Inc., New York.

Table 6-9

**MATERIALS AND EQUIPMENT REQUIRED FOR OPERATION
AND MAINTENANCE OF ENERGY FACILITIES**
(Millions of Dollars, third-quarter-1974)

Item	BEA Category
Lumber and wood products	20, 21
Paper and paper products	24-26
Chemicals and allied materials	27-32
Stone, clay, and glass products	35-36
Nonferrous metals	38
Metal products	39-42
Total materials and supplies	
Nonelectrical machinery	43-50, 52
Electrical equipment	53-58
Transportation equipment	59-61
Instruments and controls	62, 63
Miscellaneous	64
Total equipment	
Fuel (heat)	68
Electricity	68
Water	68
Total utilities	

Equipment. Equipment requirements were based on several criteria. First, equipment was segregated into items with a life expectancy equal to or greater than that of the energy facility, and those with a shorter life. Examples of these two categories are the tippie of a surface coal mine and the trucks, scrapers, and other mechanical transport equipment used at the mine. With appropriate maintenance, the tippie is expected to last for the 30-year life of the mine. The transport and similar equipment are expected to last for 5 to 7 years before replacement. Equipment costs for the tippie were those for replacement and repair supplies. (Manpower requirements were included in the overall manpower requirements for the facility.) For the transport equipment whose

life is less than that of the facility, the cost reported was a combination of an amortized replacement cost and the materials and supplies required to keep the equipment in operation over its normal lifetime. In making these assignments, published data, SRI proprietary information, and the engineering judgments of the individual analysts were employed. Equipment costs were distributed over the several categories on the basis of capital costs for each category in cases where such data were available.

Utilities. Utility requirements were derived from several sources including FPC filings and environmental impact statements. This latter source was particularly useful for some facilities in the nuclear fuel cycle.

The following utility costs were generally used to represent U.S. average third-quarter-1974 values:

- Purchased electricity - \$.015/kWh
- Purchased natural gas - \$.65/MMBtu
- Purchased fuel oil - \$.37/gal
- Purchased water - \$.25/M gal

Energy and Natural Resources Requirements Data. The model data base is also designed to include information about energy resource requirements for operating energy supply facilities associated with resource extraction. These data represent the demand for in-place energy resources of various types. Table 6-10 lists the data base categories of natural resources consumed by the operation of energy facilities and the assumed extraction efficiency:

Table 6-10

**NATURAL RESOURCES CONSUMED BY
ENERGY FACILITY OPERATION**

Resource	Unit of Consumption
Coal	quadrillion Btu
Coal	million tons
Crude oil	billion barrels
Natural gas	trillion ft ³
Oil shale	billion barrels
Uranium	thousand tons U ₃ O ₈
	Extraction Efficiency (%)
Petroleum	30 ⁽¹⁾
Natural gas	80
Coal	
Underground mine	57
Surface mine	90
Oil shale	
Underground mine	65
In-situ recovery	36
Uranium	
Surface mine	80
Underground mine	80

Note: ⁽¹⁾ Primary production only

Data Accuracy and Quality

Data review and revision procedures were similar to those described for construction resource data. Data were checked by comparing literature data where available, by consultation with industry representatives, by independent estimates and review, and by interfacility comparison of selected ratios.

Independently developed estimates agreed for major categories within ± 10 to 20 percent. The interfacility comparison was made using separate ratios of manpower, materials, and equipment to capital cost. Table D-6 in Volume II shows an array of labor and capital-cost ratios.

Accuracy estimates for a variety of facilities based on established technology, e.g. electrical power plants, uranium mills, and surface coal mines, range in the order of 10 to 20 percent. For new or developing technologies, such as in-situ shale oil, SO_2 removal, and LMFBR, accuracy estimate ranges are on the order of 20 to 50 percent. Estimates of accuracy of the data for each facility are shown in Table D-6 in Volume II.

Section 7

AN APPLICATION OF THE MODEL: THE PRESIDENT'S ENERGY PROGRAM

INTRODUCTION

Previous sections describe the methodology and the data base for the Energy Supply Planning Model. This section describes an application of the model to the President's Energy Program (January 1975) for the purpose of demonstrating the types of information that can be generated by the model from a set of input specifications.

It is emphasized that the model has been applied to one particular interpretation of the President's program, namely, the FEA interpretation described in "Draft Environmental Impact Statement of the Energy Independence Act of 1975," March 1975, Federal Energy Administration (DEIS).

While the DEIS Report presented a rather detailed picture of the 1985 fuel mix, no strategy for implementing the fuel mix was outlined. In particular, no schedules were given for the transition from the 1973 to the 1985 energy situation. For this reason, all time-dependent results should be interpreted as the results of one (of several possible) schedules of meeting the 1985 target fuel mix specified in the President's Program. In fact, the sensitivity of resource requirements to the strategy of transition between the present energy supply system and that of 1985 is analyzed in Section 8.

A summary of the highlights of the 1985 energy program is presented in this section. Following that, major results of the model application

to the program are presented. In particular, required national and regional facility schedules are shown, along with summaries of associated resource requirements for selected categories of capital, manpower, and materials.

Details of the fuel mix development are presented in Appendix C, and selected further details of computer results are tabulated in Appendix E of Volume II. In addition, a complete tabulation of all resource requirements results from this application can be found on the magnetic tape accompanying this report.

DESCRIPTION OF THE PRESIDENT'S ENERGY PROGRAM

Salient characteristics of the President's energy program, as contained in the DEIS Report, are summarized in Tables 7-1, 7-2, and 7-3. As indicated in Tables 7-1 and 7-2, annual growth rates for the 1973 to 1985 period of approximately 2.5 percent per year for total energy consumption and 6.5 percent per year for electric generation capacity are envisioned by the President's program. Major increases are targeted for the consumption of coal and nuclear fuels, along with modest increases for oil, hydroelectric power, and geothermal power, while consumption of natural gas is expected to decline. Table 7-3 presents the fuel mix in physical units.

Table 7-1

FUELS FOR TOTAL ENERGY SYSTEM⁽¹⁾ (10¹⁵ Btu)

Fuel	1973 (Actual)	1985
Coal	13.1	23.3
Oil	34.4	40.8
Gas	23.5	20.1
Nuclear	1.3	12.5
Geothermal and hydro	3.1	4.8
Total	75.4	101.5

Note: (1) Source: FEA, DEIS, March 1975 (most values)

Table 7-2
ELECTRIC POWER GENERATION⁽¹⁾

Fuel	Fuels (10 ¹⁵ Btu)		Capacity (GWe)	
	1973 Actual	1985	1973 Actual	1985
Coal	8.6	16.2	165	324
Oil ⁽²⁾	3.6	5.9	87	129
Gas	4.5	2.6	86	49
Nuclear	1.3	12.5	21	204
Geothermal and hydro	3.1	4.8	67	193
Total	21.1	42.0	426	899

Notes: (1) Source: FEA, DEIS, March 1975 (most values)

(2) Includes gas turbines

Table 7-3
1985 FUEL MIX IN PHYSICAL UNITS⁽¹⁾

Fuel	Unit
Coal	
Western	210 MM Tons
Other	900 MM Tons
Oil	
Onshore	4.3 MMBPD
Offshore	3.6 MMBPD
Alaska	5.2 MMBPD
Synthetics	0.3 MMBPD
Imports	4.7 MMBPD
Stockpile	1 billion barrels
Gas	
Onshore	6.5 TCF/Y
Offshore	5.2 TCF/Y
Alaska	7.8 TCF/Y
Synthetics	0
Imports	0
Stockpile	0

Note: (1) Source: FEA, DEIS, March 1975 (most values)

Specific features of interest include:

- Coal supply continues to be derived from traditional Eastern and Midwestern sources; Western coal contributes only 19 percent of the total tonnage in 1985.
- Production of both oil and gas shifts dramatically from onshore to offshore and Alaskan sources by 1985. Two million barrels per day of the Alaskan oil is expected to be derived from Naval Petroleum Reserve No. 4, along with another 3.2 MMBPD from other Alaskan sources.
- The DEIS Report calls for synthetic oil production of only 0.3 MMBPD (shale oil) in 1985, despite President Ford's announced target of 1 MMBPD. The use of the lower target was explained as representative of the minimum likely impact of the President's program on import levels and, therefore, the worst case imports situation.
- A rather large crude oil strategic storage system containing 1 billion barrels of crude oil for civilian use is called for.
- The President's program specifies an import level of 4.7 MMBPD of crude oil in 1985. Strategic storage and standby authorities are expected to compensate for the imports in the event of an embargo.

APPLICATION OF THE MODEL

The President's program for 1985 was converted to the required fuel mix format for input to the Energy Supply Planning Model. To complement the 1985 target fuel mix contained in the DEIS Report, values for fuel mix variables for 1977, 1980, and 1990 were developed by the study team. The national version of the model was then applied to the fuel mix to determine required energy supply and transportation facility schedules and associated resource requirements at the national level. Following that, the regional version of the model was applied to the fuel mix, using information in the DEIS Report about the location of certain types of energy supply facilities and using reference values for the remainder of the regional input variables. Regional facility schedules

and derived resource requirements, for both the construction and operation of energy-related facilities, were developed from this model application. The results of this model application are described next.

RESULTS AND ANALYSIS

The annual schedule of energy supply facility additions required to come on-line in order to satisfy the President's energy program is indicated in Figure 7-1. It should be noted that for certain requirements the construction period is longer than the number of years remaining before the required on-line dates. The fuel mix may not be feasible if these facilities (marked by *) are not currently in the appropriate engineering or construction stage.

These schedules, as well as energy transportation facility schedules, form the basis for derived schedules of direct capital, manpower, and materials for the construction and operation of energy-related facilities discussed below. All requirements are expressed without regard to the availability of such resources. Additional availability studies would be needed in combination with these estimates of resource requirements in order to establish feasibility. All capital costs are expressed in constant third-quarter-1974 dollars, unmodified by escalation factors. No owner's costs (interest during construction, lease costs, etc.) are included. Results expressed are based on outputs from the national model run, unless otherwise stated.

Capital

The annual schedule of direct capital costs required for the construction of all energy supply and transportation facilities is indicated in Figure 7-2. Ten-year (1976 to 1985) cumulative requirements amount to \$559 billion, with annual costs increasing from \$33.6 billion in 1974 to a peak of

SCHEDULE OF ANNUAL ENERGY FACILITIES ADDITIONS TO SUPPLY FUEL MIX NO. 1975 STATE OF UNION-M56.-EIA90 1974-1990

FACILITY NAME	1973 TOTALS	1974	1975	1976	1977	1978	1979	1980	TOTAL ADDED
1 ONSHORE OIL PRODUCTION-LOWER 48 (1.25 MB/D)	41939.0	1508*	1542*	0	0	0	0	0	3050
2 OFFSHORE OIL PRODUCTION-LOWER 48 (4 MB/D)	01.0	3*	3*	33*	33*	33*	33*	32	170
3 ALASKAN OIL PRODUCTION (100 MB/D)	0.0	0	0	1*	1*	1*	1*	2	6
4 HIGH-GASOLINE REFINERY (200 MB/D)	53.0	0	1*	1*	0	3*	3*	3*	11
5 LOW-GASOLINE REFINERY (200 MB/D)	28.0	0	1*	1*	0	0	0	0	2
6 HEAVY FUEL OIL GASIFICATION (250 MMCF/D)	0.0	0	0	0	0	0	0	0	0
7 NAPHTHA GASIFICATION (175 MMCF/D)	0.0	0	0	0	0	0	0	0	0
8 CRUDE OIL STOCKPILE (50 MMDBL)	0.0	0	0	0	0	0	0	0	0
9 ALASKAN OIL EXPORT (2000 MB/D)	0.0	0	0	1*	0	0	0	0	1
10 OFFSHORE CRUDE OIL IMPORT (1700 MB/D)	0.0	0	0	0	0	0	0	0	0
11 ONSHORE OIL IMPORT (1000 MB/D)	0.0	0	0	0	0	0	0	0	0
12 OIL SHALE PINE (150000 TONS/D)	0.0	0	0	0	0	0	0	0	0
13 IN SITU SHALE OIL RECOVERY (37 MB/D OIL)	0.0	0	0	0	0	0	0	0	0
14 OIL SHALE RETORTING AND UPGRADING (90 MB/D)	0.0	0	0	0	0	0	0	0	0
15 SHALE OIL UPGRADING (90 MB/D OIL)	0.0	0	0	0	0	0	0	0	0
16 ONSHORE GAS PRODUCTION-LOWER 48 (3 MMCF/D)	15624.0	432*	429*	237*	237*	321*	33*	33*	2315
17 OFFSHORE GAS PRODUCTION-LOWER 48 (50 MMCF/D)	130.0	4*	4*	23*	22*	22*	22*	21	110
18 ALASKAN GAS PRODUCTION (250 MMCF/D)	0.0	0	0	0	0	0	0	0	0
19 COAL MINE DEGASIFICATION (1 MMCF/D)	0.0	0	0	0	0	0	0	0	0
20 ALASKAN LNG EXPORT (3000 MMCF/D)	0.0	0	0	0	0	0	0	0	0
21 LNG IMPORT (2795 MMCF/D)	0.0	0	0	0	0	0	0	0	0
22 NATURAL GAS STOCKPILE (66 MILLION CF)	0.0	0	0	0	0	0	0	0	0
23 UNDERGROUND EASTERN COAL MINE (2 MMT/Y)	124.0	16*	15*	12*	12*	13*	13*	12	91
24 SURFACE EASTERN COAL MINE (6 MMT/Y)	50.0	5*	6*	6*	6*	6*	6*	7	42
25 SURFACE WESTERN COAL MINE (6 MMT/Y)	12.0	0	1*	2*	1*	2*	3	2	11
26 UNDERGROUND WESTERN COAL MINE (2 MMT/Y)	0.0	0	0	1*	0	0	1*	0	2
27 COAL GASIFICATION - HIGH BTU (250 MMCF/D)	0.0	0	0	0	0	0	0	0	0
28 COAL GASIFICATION - LOW & MED-BTU (1440 MMCF/D)	0.0	0	0	0	0	0	0	0	0
29 COAL GASIFICATION - METHANOL (15000 TONS/D)	0.0	0	0	0	0	0	0	0	0
30 COAL LIQUEFACTION-HEAVY FUEL OIL (21.7 MB/D)	0.0	0	0	0	0	0	0	0	0
31 COAL SOLVENT REFINING - SRC (4560 TONS/D SRC)	0.0	0	0	0	0	0	0	0	0
32 COAL LIQUIDS REFINERY (100 MB/D)	0.0	0	0	0	0	0	0	0	0
33 SURFACE URANIUM MINE (1200 TONS/D ORE)	13.0	3*	3*	7*	3*	2*	4*	4*	21

* - THE CONSTRUCTION SCHEDULE FOR THIS FACILITY IS LONGER THAN THE NUMBER OF YEARS BETWEEN THE PRESENT AND THE ON-LINE DATE. IF THE FACILITY IS NOT CURRENTLY IN THE APPROPRIATE ENGINEERING OR CONSTRUCTION STAGE, THE FUEL MIX MAY NOT BE FEASIBLE.

Figure 7-1. Schedule of Annual Energy Supply Facility Additions

SCHEDULE OF ANNUAL ENERGY FACILITIES ADDITIONS TO SUPPLY FUEL MIX NO. 1975 STATE OF UNION-MS6--EIA98 1974-1990

FACILITY NAME	1973 TOTALS	1974	1975	1976	1977	1978	1979	1980	TOTAL ADDED
34 UNDERGROUND URANIUM MINE (500 TONS/D ORE)	37.0	9*	9*	7*	6*	8*	11*	11	61
35 URANIUM MILL (1000 T/D ORE)	26.0	6*	6*	5*	5*	5*	8	8	43
36 URANIUM CONVERSION (9090 MTU/Y YELLOWCAKE)	2.0	0	1*	0	0	0	1*	0	2
37 URANIUM ENRICHMENT-DIFFUSION (8750 MT SWU/YR)	3.0	0	0	0	0	0	0	0	0
38 LWR FUEL FABRICATION-NO PU RECYCLE (600MTU/Y)	2.0	0	1*	0	1*	0	1*	0	3
39 LWR FUEL FABRICATION - PU RECYCLE (150 MTU/Y)	0.0	0	0	0	0	0	0	4	4
40 HTGR FUEL FABRICATION (450 MTU/Y)	0.0	0	0	0	0	0	0	0	0
41 FBR FUEL FABRICATION (315 MTU/Y)	0.0	0	0	0	0	0	0	0	0
42 LWR SPENT FUEL REPROCESSING (1500 MTU/Y)	0.0	0	0	1*	0	0	1*	0	2
43 HTGR SPENT FUEL REPROCESSING (300 MTU/Y)	0.0	0	0	0	0	0	0	0	0
44 FBR SPENT FUEL REPROCESSING (950 MTU/Y)	0.0	0	0	0	0	0	0	0	0
45 HIGH-LEVEL WASTE DISPOSAL (3100 CANISTERS/YR)	0.0	0	0	0	0	0	0	0	0
46 SOLID WASTE COLLECTION/SEPARATION PT.(1335 T/D)	0.0	0	0	0	0	0	0	0	0
47 OIL-FIRED POWER PLANT (800 MWE)	43.0	0	0	0	0	0	0	0	0
48 RECONVERSION OF OIL PLANT TO COAL (250 MWE)	0.0	13*	12*	12*	11	0	0	0	48
49 COAL FIRED POWER PLANT-LOW BTU (800 MWE)	17.0	1*	1*	3*	3*	3*	4*	5*	20
50 COAL FIRED POWER PLANT-HIGH BTU (800 MWE)	190.0	15*	14*	14*	13*	22*	22*	21*	121
51 COAL/WASTE POWER PLANT-LO BTU COAL (350 MWE)	0.0	0	0	0	0	0	0	0	0
52 COAL/WASTE POWER PLANT-HI BTU COAL (350 MWE)	0.0	0	0	0	0	0	0	0	0
53 SULFUR OXIDE REMOVAL (800 MWE)	0.0	0	0	10*	10*	13*	14	15	62
54 LOW/INTERMEDIATE-BTU GAS FIRED PLANT (1000MWE)	0.0	0	0	0	0	0	0	0	0
55 HIGH BTU GAS-FIRED POWER PLANT (800 MWE)	100.0	0	0	0	0	0	0	0	0
56 COMBINED CYCLE POWER PLANT (400 MWE)	1.0	1*	0	1*	0	1*	1*	0	4
57 GAS TURBINE POWER PLANT (133 MWE)	151.0	37*	38*	38*	37*	50	50	51	301
58 FUEL CELLS (26 MWE)	0.0	0	0	0	0	0	0	0	0
59 LIGHT WATER REACTOR (LWR) (1100 MWE)	20.0	10*	10*	10*	9*	0*	0*	7*	62
60 HIGH TEMP GAS REACTOR (HTGR) (1500 MWE)	0.0	0	0	0	0	0	0	0	0
61 FAST BREEDER REACTOR -LMFBR (1000MWE)	0.0	0	0	0	0	0	0	0	0
62 DAM & HYDROELECTRIC POWER PLANT (200 MWE)	303.0	6*	6*	6*	6*	6*	6*	6*	42
63 PUMPED STORAGE (1000 MWE)	6.0	3*	2*	2*	2*	11*	11*	11*	42
64 GEOTHERMAL POWER COMPLEX (200 MWE)	2.0	0	0	0	0	0	0	0	0
65 SOLAR SPACE HEATING (30000 DWELLINGS)	0.0	0	0	0	0	0	0	0	0
66 SOLAR SPACE CONDITIONING (30000 DWELLINGS)	0.0	0	0	0	0	0	0	0	0

* - THE CONSTRUCTION SCHEDULE FOR THIS FACILITY IS LONGER THAN THE NUMBER OF YEARS BETWEEN THE PRESENT AND THE ON-LINE DATE. IF THE FACILITY IS NOT CURRENTLY IN THE APPROPRIATE ENGINEERING OR CONSTRUCTION STAGE, THE FULL MIX MAY NOT BE FEASIBLE.

Figure 7-1. (Continued)

SCHEDULE OF ANNUAL ENERGY FACILITIES ADDITIONS TO SUPPLY FUEL MIX NO. 1975 STATE OF UNION-M56.-EIA90 1974-1990

FACILITY NAME	1981	1982	1983	1984	1985	TOTAL ADDED
1 ONSHORE OIL PRODUCTION-LOWER 48 (1.25 MB/D)	0	0	0	0	0	3050
2 OFFSHORE OIL PRODUCTION-LOWER 48 (4 MB/D)	130	132	144	156	168	900
3 ALASKAN OIL PRODUCTION (180 MB/D)	4	4	5	4	4	31
4 HIGH-GASOLINE REFINERY (200 MB/D)	0	1	3	4	3	29
5 LOW-GASOLINE REFINERY (200 MB/D)	0	1	2	3	3	11
6 HEAVY FUEL OIL GASIFICATION (250 MMCF/D)	0	0	0	0	0	0
7 NAPHTHA GASIFICATION (174 MMCF/D)	0	0	0	0	0	0
8 CRUDE OIL STOCKPILE (50 MMBBL)	4	4	4	4	4	20
9 ALASKAN OIL EXPORT (2000 MB/D)	0	1	0	1	0	3
10 OFFSHORE CRUDE OIL IMPORT (1700 MB/D)	0	0	0	0	0	0
11 ONSHORE OIL IMPORT (1800 MB/D)	1	1	1	1	2	6
12 OIL SHALE MINE (150000 TONS/D)	1	1	1	0	2	5
13 IN SITU SHALE OIL RECOVERY (137 MB/D OIL)	0	0	0	0	0	0
14 OIL SHALE RETORTING AND UPGRADING (90 MB/D OIL)	10	1	1	0	2	5
15 SHALE OIL UPGRADING (90 MB/D OIL)	0	0	0	0	0	0
16 ONSHORE GAS PRODUCTION-LOWER 48 (13 MMCF/D)	0	0	0	0	0	2315
17 OFFSHORE GAS PRODUCTION-LOWER 48 (50 MMCF/D)	26	26	24	23	21	230
18 ALASKAN GAS PRODUCTION (250 MMCF/D)	1	3	3	2	2	11
19 COAL MINE GASIFICATION (1 MMCF/D)	0	0	0	0	0	0
20 ALASKAN LNG EXPORT (3030 MMCF/D)	10	0	1	0	0	2
21 LNG IMPORT (2795 MMCF/D)	1	0	1	0	0	2
22 NATURAL GAS STOCKPILE (66 BILLION CF)	0	0	0	0	0	0
23 UNDERGROUND EASTERN COAL MINE (12 MMT/Y)	7	7	7	7	7	125
24 SURFACE EASTERN COAL MINE (4 MMT/Y)	4	4	4	4	4	62
25 SURFACE WESTERN COAL MINE (6 MMT/Y)	2	1	2	2	2	20
26 UNDERGROUND WESTERN COAL MINE (12 MMT/Y)	1	0	0	1	0	4
27 COAL GASIFICATION - HIGH BTU (250 MMCF/D)	0	0	0	0	0	0
28 COAL GASIFICATION-LOW & MED-BTU(1440 MMCF/D)	0	0	0	0	0	0
29 COAL GASIFICATION - METHANOL (15000 TONS/D)	0	0	0	0	0	0
30 COAL LIQUEFACTION-HEAVY FUEL OIL (21.7 MB/D)	0	0	0	0	0	0
31 COAL SOLVENT REFINING - SRC (4560 TONS/D SRC)	0	0	0	0	0	0
32 COAL LIQUIDS REFINERY (100 MB/D)	0	0	0	0	0	4
33 SURFACE URANIUM MINE (1200 TONS/D ORE)	4	3	4	4	5	41

* - THE CONSTRUCTION SCHEDULE FOR THIS FACILITY IS LONGER THAN THE NUMBER OF YEARS BETWEEN THE PRESENT AND THE ON-LINE DATE. IF THE FACILITY IS NOT CURRENTLY IN THE APPROPRIATE ENGINEERING OR CONSTRUCTION STAGE, THE FUEL MIX MAY NOT BE FEASIBLE.

Figure 7-1. Continued)

SCHEDULE OF ANNUAL ENERGY FACILITIES ADDITIONS TO SUPPLY FUEL MIX NO. 1975 STATE OF UNION-MSB.-EIA90 1974-1990

FACILITY NAME	1981	1982	1983	1984	1985	TOTAL ADDED
34 UNDERGROUND URANIUM MINE (500 TONS/D ORE)	10	9	9	13	13	115
35 URANIUM MILL (1000 T/D ORE)	7	7	7	9	9	82
36 URANIUM CONVERSION (9000 MTU/Y YELLOWCAKE)	1	0	0	1	0	4
37 URANIUM ENRICHMENT-DIFFUSION (8750 MT SWU/YR)	0	0	0	1*	0	1
38 LWR FUEL FABRICATION-NO PU RECYCLE (6000MTU/Y)	0	0	0	0	0	3
39 LWR FUEL FABRICATION - PU RECYCLE (1150 MTH/Y)	5	6	8	9	6	34
40 HTGR FUEL FABRICATION (450 MTH/Y)	0	1	0	0	0	1
41 FBR FUEL FABRICATION (315 MTH/Y)	0	0	0	0	0	0
42 LWR SPENT FUEL REPROCESSING (1500 MTU/Y)	0	0	0	1	0	3
43 HTGR SPENT FUEL REPROCESSING (300 MTH/Y)	0	0	0	0	0	0
44 FBR SPENT FUEL REPROCESSING (950 MTH/Y)	0	0	0	0	0	0
45 HIGH-LEVEL WASTE DISPOSAL (3100 CANISTERS/YR)	0	0	0	0	0	0
46 SOLID WASTE COLLECTION/SEPARATION PT. (1335 T/D)	0	0	0	0	0	0
47 OIL-FIRED POWER PLANT (800 MWE)	0	0	0	0	0	0
48 RECONVERSION OF OIL PLANT TO COAL (250 MWE)	0	0	0	0	0	0
49 COAL FIRED POWER PLANT-LOW BTU (800 MWE)	3	3	4	3	4	37
50 COAL FIRED POWER PLANT-HIGH BTU (800 MWE)	13	13	12	12	12	104
51 COAL/WASTE POWER PLANT-LO BTU COAL (350 MWE)	0	0	0	0	0	0
52 COAL/WASTE POWER PLANT-HI BTU COAL (350 MWE)	0	0	0	0	0	0
53 SULFUR OXIDE REMOVAL (800 MWE)	20	22	22	24	24	174
54 LOW/INTERMEDIATE-BTU GAS FIRED PLANT (800MWE)	0	0	0	0	0	0
55 HIGH BTU GAS-FIRED POWER PLANT (800 MWE)	0	0	0	0	0	0
56 COMBINED CYCLE POWER PLANT (400 MWE)	1	0	1	0	1	7
57 GAS TURBINE POWER PLANT (133 MWE)	30	30	30	30	30	451
58 FUEL CELLS (20 MWE)	0	0	0	0	0	0
59 LIGHT WATER REACTOR (LWR) (1100 MWE)	20*	20*	10*	10*	10	150
60 HIGH TEMP GAS REACTOR (HTGR) (1500 MWE)	1*	1*	1*	1*	2	6
61 FAST BREEDER REACTOR -LMFBR (1000MWE)	0	0	0	0	0	0
62 DAM & HYDROELECTRIC POWER PLANT (200 MWE)	6	6	6	7	4	73
63 PUMPED STORAGE (1000 MWE)	14*	14*	14	14	13	111
64 GEOTHERMAL POWER COMPLEX (200 MWE)	0	0	0	0	0	0
65 SOLAR SPACE HEATING (30000 DWELLINGS)	0	0	0	0	0	0
66 SOLAR SPACE CONDITIONING (30000 DWELLINGS)	0	0	0	0	0	0

* - THE CONSTRUCTION SCHEDULE FOR THIS FACILITY IS LONGER THAN THE NUMBER OF YEARS BETWEEN THE PRESENT AND THE ON-LINE DATE. IF THE FACILITY IS NOT CURRENTLY IN THE APPROPRIATE ENGINEERING OR CONSTRUCTION STAGE, THE FUEL MIX MAY NOT BE FEASIBLE.

Figure 7-1 (Continued)

\$62.4 billion in 1983. These costs are disaggregated by facility grouping, by energy sector, and by function in Table 7-4 and Figures 7-3 and 7-4.

Ten-year cumulative capital costs by energy sector are:

- Electric utilities (including generation, transmission, and distribution): \$411 billion
- Oil: \$81 billion } 11⁴
- Gas: \$33 billion }
- Coal and synthetic fuels: \$21 billion
- Nuclear fuel cycle (excluding power plant): \$14 billion

When broken down by function, the following results obtain:

- Energy extraction and conversion: \$314 billion
- Electricity transmission and distribution: \$203 billion
- All other energy transportation: \$42 billion

The most significant finding is the dominance of electric utility capital costs in the President's energy program, amounting to approximately 74 percent of the total energy industry investments for the 1976 to 1985 period. Of this total, generation accounts for \$208 billion, transmission for \$51 billion, and distribution for \$152 billion. This result would appear to derive both from the capital-intensive nature of electric power-related facilities and from the relatively high growth rate of 6.5 percent per year for the electric power sector in the President's program, compared to only 2.5 percent for the total energy system. As shown previously in Tables 7-1 and 7-2, the electric sector accounts for 20.9×10^{15} Btu of the 26.1×10^{15} Btu total growth in fuels requirements over the 1973 to 1985 period for this program.

The fact that the energy industries will need to raise an average of \$56 billion per year through 1985 (up from \$34 billion in 1974) clearly raises the question of the feasibility of meeting these requirements. The question of the availability of adequate capital, not addressed in this study, is a significant area for future work.

Table 7-4

**TEN-YEAR (1976-1985) CUMULATIVE CAPITAL
REQUIREMENTS OF THE ENERGY INDUSTRY,
BY FACILITY GROUPING⁽¹⁾**

Facility	Capital (\$ Billions)
OIL	
Exploration, development, and production	32.0
Refining and processing	22.7
Pipelines	8.9
Tankers, barges, trucks	6.1
Bulk stations	1.0
Other	<u>4.2</u>
Total oil	74.9
OIL SHALE	5.8
GAS	
Exploration, development, and production	19.5
Pipelines	4.2
LNG tankers	2.8
Distribution	2.9
Other	<u>3.3</u>
Total gas	32.7
COAL	
Mining	9.4
Transportation	<u>9.0</u>
Total coal	18.4
COAL SYNTHETICS	2.2
NUCLEAR FUEL CYCLE	14.0
SOLAR	0.0
ELECTRIC UTILITIES	
Coal-fired	47.8
Nuclear	116.1
Hydro and pumped storage	24.6
Oil and gas	6.1
Geothermal	<u>0.0</u>
Total Generation	194.6
Transmission	51.1
Distribution	151.8
Sulfur-removal facilities	<u>13.8</u>
Total utilities	411.3
TOTAL CAPITAL COSTS	559.3

Note: ⁽¹⁾ All costs are as constructed in 3rd-quarter-1974
fixed dollars (owner's costs excluded)

*Includes costs as constructed in third quarter - 1974 fixed dollars (owners costs excluded) for the design, construction and startup of energy supply and transportation facilities.

Figure 7-2. Annual Schedule of Direct Capital Requirements of the Energy Industry

*All costs are as constructed in third quarter - 1974 fixed dollars (owners costs excluded). Includes costs for energy supply and energy transportation facilities.

Figure 7-3. Ten-Year (1976-1985) Cumulative Capital Requirements of the Energy Industry, by Energy Sector*

*All costs are as constructed in third quarter - 1974 fixed dollars (owners costs excluded). Includes costs for energy supply and energy transportation facilities.

Figure 7-4. Ten-Year (1976-1985) Cumulative Capital Requirements of the Energy Industry, by Function*

Manpower

Figure 7-5 indicates the annual schedule of direct requirements for engineers, craftsmen, and teamsters and laborers for the design, construction, and startup of energy supply and transportation facilities.

Results indicate that:

- The number of engineers required increases from 51,000 in 1974 to a peak annual requirement of 98,000, with an average annual requirement for the 1976 to 1985 period of 87,000 engineers
- The number of craftsmen required increases from 215,000 in 1974 to a peak annual requirement of 424,000, with an average annual requirement for the 1976 to 1985 period of 341,000 craftsmen
- The number of teamsters and laborers required increases from 66,000 in 1974 to a peak annual requirement of 142,000 with an average annual requirement for the 1976 to 1985 period of 127,000 teamsters and laborers

The growth rates for the various requirements are given below:

	(%/Y) <u>1974-1980</u>	(%/Y) <u>1980-1985</u>	Overall (%/Y) <u>1974-1985</u>
Engineers	9.5	1.9	6.0
Craftsmen	9.8	2.2	6.3
Teamsters and laborers	12.3	1.3	7.2

With total population and labor force growing quite slowly, as is the number of engineering graduates, the indicated rates of increase of 9 percent to 13 percent per year for the duration of the 1970's are rather startling. The 1980 to 1985 projected growth rates are comparatively quite low. * The shortage of engineering graduates appears even more serious because recent figures on enrollment in

* Note that these results depend to some degree on the particular strategy (schedule) selected to arrive at the President's 1985 program, and that this strategy was not spelled out in the source DEIS Report.

the graduating classes of 1975 to 1978 indicate no increase in new graduates for this period above the 1970 to 1974 quantities.

A careful analysis of the supply of manpower resources (not included in this study) is needed to investigate the feasibility of meeting the above requirements.

Figure 7-6 presents the annual schedule of direct requirements for engineers, craftsmen, and teamsters and laborers for the normal operation and maintenance of energy-related facilities. Results indicate that:

- The number of engineers decreases from 83,000 in 1974 to 79,000 in 1985, with an average annual requirement for the 1976 to 1985 period of 81,000 engineers.
- The number of craftsmen increases from 564,000 in 1974 to 710,000 in 1985, with an average annual requirement for the 1976 to 1985 period of 639,000 craftsmen.
- The number of teamsters and laborers increases from 141,000 in 1974 to 196,000 in 1985, with an average annual requirement for the 1976 to 1985 period of 170,000 teamsters and laborers.

The counter-intuitive decrease in the requirement for operations engineering appears to derive from the dramatic shift in the President's energy program from onshore sources of oil and gas — which are quite engineering-intensive in operations requirements — to offshore and Alaskan sources of production, which are less so.

However, because of the relatively high degree of uncertainty in resource requirements data for oil and gas exploration, development, and production, compared to that for other facilities, this result would need to be further investigated before attaining a high degree of confidence level.

*INCLUDES REQUIREMENTS FOR ENERGY SUPPLY AND TRANSPORTATION FACILITIES.

Figure 7-5. Annual Schedule of Direct Manpower Requirements for the Design, Construction, and Startup of Energy-Related Facilities*

*INCLUDES REQUIREMENTS FOR ENERGY SUPPLY AND TRANSPORTATION FACILITIES.

Figure 7-6. Annual Schedule of Direct Manpower Requirements for the Normal Operation and Maintenance of Energy-Related Facilities*

Energy Resources

Table 7-5 presents the ten-year (1976 to 1985) cumulative requirements for total energy resources of crude oil, shale oil, natural gas, coal, and uranium. The figures represent the total consumption of energy resources, accounting both for the resources delivered to the energy system and those left in place due to resource extraction inefficiencies. Table 7-6 presents the associated values for resources actually delivered to the energy system.

Table 7-5

TEN-YEAR (1976-1985) CUMULATIVE ENERGY RESOURCES CONSUMPTION⁽¹⁾

Resource	Consumption
Crude oil	155 billion barrels
Shale oil	<1 billion barrels
Natural gas	228 trillion cubic feet
Coal	11.7 billion tons
Uranium	869 thousand tons U_3O_8

Note: ⁽¹⁾ Total resource consumption (e.g. includes coal left in place, etc.)

Table 7-6

TEN-YEAR (1976-1985) CUMULATIVE ENERGY RESOURCES DELIVERED TO ENERGY SYSTEM⁽¹⁾

Resource	Amount Delivered
Crude oil	46.5 billion barrels
Shale oil	<1.0 billion barrels
Natural gas	182 trillion cubic feet
Coal	8.3 billion tons
Uranium	695 thousand tons U_3O_8

Note: ⁽¹⁾ Delivered resource consumption (e.g. excludes coal left in place, etc.)

Regional Impacts

The ten-year (1976 to 1985) cumulative energy supply facility additions required to come on-line in each region are summarized in Table 7-7. These regional results were derived from application of the regional version of the model to the President's energy program, as stated previously (the 14 model regions are shown as Figure 2-4 in Section 2 of this volume). These regional schedules were then used to derive regional energy transportation facility requirements and regional resource requirements for the construction and operation of energy-related facilities.

Figure 7-7 summarizes the regional results of this application in terms of ten-year (1976 to 1985) cumulative capital investments in each of the 14 model regions. Construction activity in the various model regions can be summarized as follows:

- Greater than \$5 billion per year: Mid-Atlantic, South Atlantic, East North Central, East South Central, West South Central Regions
- \$2.5 to \$5 billion per year: West North Central, Northern Pacific, Southern Pacific Regions
- Less than \$2.5 billion per year: Northeast, Northern Mountain, Southern Mountain, and the three coastal (offshore) regions

Table 7-7

TEN-YEAR (1976-1985) CUMULATIVE ENERGY SUPPLY FACILITY ADDITIONS

Facility	Regions													
	Northeast-1	Mid-Atlantic-2	South Atlantic-3	East North Central-4	East South Central-5	West North Central-6	West South Central-7	Northern Mountain-8	Southern Mountain-9	Northern Pacific-10	Southern Pacific-11	Atlantic Coastal-12	Gulf Coastal-13	Pacific Coastal-14
1 Onshore oil production - lower 48 (1.25 MBPD)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2 Offshore oil production - lower 48 (4 MBPD)	0	0	0	0	0	0	0	0	0	0	0	223	224	447
3 Alaskan oil production (180 MBPD)	0	0	0	0	0	0	0	0	0	31	0	0	0	31
4 High-gasoline refinery (200 MBPD)	0	0	15	0	0	0	5	0	0	0	0	0	0	25
5 Low-gasoline refinery (200 MBPD)	0	0	5	0	0	0	2	0	0	0	0	0	0	9
6 Heavy fuel oil gasification (250 MMCF/D)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7 Naphtha gasification (174 MMCF/D)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8 Crude oil stockpile (50 MMBSL)	0	0	0	0	0	0	20	0	0	0	0	0	0	20
9 Alaskan oil export (2,000 MBPD)	0	0	0	0	0	0	0	0	0	3	0	0	0	3
10 Offshore crude oil import (1,700 MBPD)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11 Onshore oil import (1,000 MBPD)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12 Oil shale mine (150,000 TONS/D)	0	0	0	0	0	0	0	1	4	0	0	0	0	5
13 In-situ shale oil recovery (37 MBPD OIL)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14 Oil shale retorting and upgrading (90 MBPD OIL)	0	0	0	0	0	0	0	1	5	0	0	0	0	6
15 Shale oil upgrading (90 MBPD OIL)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16 Onshore gas production - lower 48 (3MMCF/D)	0	4	14	8	11	60	1,182	27	109	0	39	0	0	1,454
17 Offshore gas production - lower 48 (3MMCF/D)	0	0	0	0	0	0	0	0	0	0	0	10	202	230
18 Alaskan gas production (250 MMCF/D)	0	0	0	0	0	0	0	0	0	11	0	0	0	11
19 Coal mine degasification (1 MMCF/D)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20 Alaskan LNG export (3,030 MMCF/D)	0	0	0	0	0	0	0	0	0	2	0	0	0	2
21 LNG import (2,795 MMCF/D)	0	0	0	0	0	0	0	0	0	0	2	0	0	2
22 Natural gas stockpile (66 BILLION CF)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23 Underground Eastern coal mine (2 MMT/Y)	0	1	3	38	54	0	0	0	0	0	0	0	0	96
24 Surface Eastern coal mine (4 MMT/Y)	0	5	11	14	13	2	6	0	0	0	0	0	0	51
25 Surface Western coal mine (6 MMT/Y)	0	0	0	0	0	0	0	13	0	0	0	0	0	19
26 Underground Western coal mine (2 MMT/Y)	0	0	0	0	0	0	0	4	0	0	0	0	0	4
27 Coal gasification (high-Btu) (250 MMCF/D)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28 Coal gasification (low- and medium-Btu) (1,440 MMCF/D)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 Coal gasification (methanol) (15,000 TONS/D)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30 Coal liquefaction (heavy fuel oil) (21.7 MBPD)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 Coal solvent refining - SRC (4,560 TONS/D SRC)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 Coal liquids refinery (100 MBPD)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 Surface uranium mine (1,200 TONS/D ore)	0	0	0	0	0	0	2	13	18	2	0	0	0	35
34 Underground uranium mine (500 TONS/D ore)	0	0	0	0	0	0	4	38	50	5	0	0	0	97
35 Uranium mill (5,000 TONS/D)	0	0	0	0	0	0	3	27	37	3	0	0	0	70
36 Uranium conversion (9,090 MTU/Y yellowcake)	0	1	1	0	0	0	1	0	0	0	0	0	0	3
37 Uranium enrichment - diffusion (8,750 MT SWU/Y)	0	0	0	0	1	0	0	0	0	0	0	0	0	1
38 LWR fuel fabrication - no Pu recycle (600 MTU/Y)	1	0	1	0	0	0	0	0	0	0	0	0	0	2
39 LWR fuel fabrication - Pu recycle (150 MTH/Y)	0	4	13	0	4	0	4	0	0	4	9	0	0	38
40 HTGR fuel fabrication (450 MTH/Y)	0	0	1	0	0	0	0	0	0	0	0	0	0	1
41 FBR fuel fabrication (315 MTH/Y)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42 LWR spent fuel reprocessing (1,500 MTU/Y)	0	0	3	0	0	0	0	0	0	0	0	0	0	3
43 HTGR spent fuel reprocessing (300 MTH/Y)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 FBR spent fuel reprocessing (950 MTH/Y)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 High-level waste disposal (3,100 canisters/Y)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46 Solid waste collection/separation pt. (335 T/D)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
47 Oil-fired power plant (800 MWe)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
48 Reconversion of oil plant to coal (250 MWe)	4	8	8	2	0	0	0	0	0	0	0	0	0	22
49 Coal-fired power plant low-Btu (800 MWe)	0	0	0	5	0	5	0	7	9	1	8	0	0	35
50 Coal-fired power plant high-Btu (800 MWe)	3	8	31	54	28	0	31	0	0	0	0	0	0	155
51 Coal/waste power plant low-Btu coal (350 MWe)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52 Coal/waste power plant high-Btu coal (350 MWe)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53 Sulfur oxide removal (800 MWe)	0	26	43	70	35	0	0	0	0	0	0	0	0	174
54 Low/intermediate-Btu gas-fired plant (800 MWe)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55 High-Btu gas-fired power plant (800 MWe)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56 Combined-cycle power plant (400 MWe)	1	1	1	0	1	1	2	0	0	0	0	0	0	7
57 Gas-turbine power plant (133 MWe)	0	0	90	90	90	12	57	4	8	4	23	0	0	378
58 Fuel cells (26 MWe)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59 Light water reactor (LWR) (1,100 MWe)	7	24	26	5	29	18	13	0	1	9	5	0	0	157
60 High temp gas reactor (HTGR) (1,500 MWe)	0	1	1	0	1	1	1	0	0	0	0	0	0	5
61 Fast breeder reactor LMFBR (1,000 MWe)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62 Dam and hydroelectric power plant (200 MWe)	4	3	2	4	3	1	1	0	1	23	18	0	0	60
63 Pumped storage (1,000 MWe)	8	4	3	8	7	1	1	0	2	41	32	0	0	107
64 Geothermal power complex (200 MWe)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
65 Solar space heating (30,000 dwellings)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66 Solar space conditioning (30,000 dwellings)	0	0	0	0	0	0	0	0	0	0	0	0	0	0

• ALL COSTS ARE AS CONSTRUCTED IN 3rd-QUARTER-1974 FIXED DOLLARS (OWNER'S COSTS EXCLUDED). INCLUDES COSTS FOR ENERGY SUPPLY AND TRANSPORTATION FACILITIES.

Figure 7-7. Ten-Year (1976-1985) Cumulative Capital Requirements of the Energy Industry, by Region

Section 8

SENSITIVITY OF SELECTED RESOURCES REQUIREMENTS TO ALTERNATIVE ENERGY SCENARIOS

INTRODUCTION

Section 7 describes an application of the Energy Supply Planning Model to the President's energy program to demonstrate the categories of information that can be generated by the model from a set of variables specifying a future state of the energy system. This section demonstrates the use of the model to trace the effects of various energy policy options on these information categories. To accomplish this, the President's energy program has been used as a base case, and the effect of various changes to the base case fuel mix have been derived.

The intent of this activity is to identify the impacts of one policy variable at a time, rather than to generate whole sets of new results based on substantially different fuel mixes. In the following discussion, scenarios are developed to simulate various policy options and are described in terms of the one specific change made to the base case. The implications of the change on a selected set of resource requirements are then presented. These results are based on national model application unless otherwise stated. Seven policy variables are analyzed in this manner:

- Construction schedule strategy
- Decrease in the growth rate of electricity consumption
- Increase in power plant capacity factors
- Shift from nuclear to coal-fired electric power generation
- Decrease in gasoline consumption
- Increase in oil imports
- Accelerated Western coal development

SCENARIO NO. 1: CONSTRUCTION SCHEDULE STRATEGY

It was pointed out in describing the President's energy program that the DEIS Report did not specify a strategy for implementing the transition between the present state of the energy system and that of 1985 and that the model was applied to one particular (of several possible) construction schedule strategy. This scenario is designed to test the sensitivity of the time-dependent results for selected capital and manpower categories.

Description of the Scenario

The President's energy program for 1985 supply levels was maintained. However, the 1980 levels of supply for certain fuels were decreased, as compared to those of the base case, to reflect a slower start toward the President's 1985 target. Energy options chosen for a decrease in their 1980 production capacities were selected on the basis that 1980 intermediate targets were higher than are likely to be feasible based on current construction activities (subjective judgment). Targets for 1980 for the following options were decreased on this basis:

- Coal-fired power (6 percent lower)
- Hydro and pumped storage (33 percent lower)
- Offshore oil production (33 percent lower)
- Offshore gas production (25 percent lower)

Results and Analysis

Figures 8-1 and 8-2 present results of model application to this scenario. Annual schedules of capital and manpower (engineers and craftsmen) for the construction of all energy supply and transportation facilities for the base case are compared to the construction schedule delays case. Delays in starting towards the President's 1985 targets imply lower resource requirements during the 1970's but higher requirements during the 1980's. It should be noted that cumulative capital costs are essentially identical for the period covered, as may be expected. Perhaps a more significant implication is that the peak annual requirements and the peak-to-average

ratios are somewhat greater under the situation of construction schedule delays. For example, in the case of capital:

- Peak capital requirement is \$70 billion vs \$62 billion for the base case
- Peak-to-average capital ratio is 1.33 vs 1.19 for the base case

*Includes capital for construction of energy supply and transportation facilities.

Figure 8-1. Sensitivity of Capital Requirements

*Includes requirements for the construction of energy supply and transportation facilities.

Figure 8-2. Sensitivity of Manpower Requirements

SCENARIO NO. 2: DECREASE IN THE GROWTH RATE OF ELECTRICITY CONSUMPTION

Description of Scenario

A decrease of one percent per year in the growth rate of electricity consumption represents a decrease in the average annual 1973 to 1985 growth rate for electric power from 6.5 percent per year to 5.5 percent per year. This corresponds to an approximate decrease in total (base case) 1985 generation capacity of 100 GWe. This decrease was assumed to occur in new base-load coal and nuclear power capacities in the President's energy program in proportion to the base case requirements for new capacity of the two types.

Results and Analysis

Table 8-1 presents the implications of this scenario in terms of ten-year (1976-1985) cumulative requirements of selected resources for the construction of energy supply and transportation facilities. Requirements decline by 18 to 20 percent from the base case results. Specifically:

- Total capital requirements are reduced by \$102 billion
- Number of engineers (average annual) required decreases by 17,000
- Number of craftsmen (average annual) required decreases by 73,000
- Number of teamsters and laborers required decreases by 25,000

Table 8-1

SENSITIVITY OF SELECTED CONSTRUCTION CAPITAL AND MANPOWER REQUIREMENTS TO A DECREASE IN ELECTRICITY CONSUMPTION

Resource Requirements for Energy Supply and Transportation Facilities	1976-85 Cumulative		
	Base Case	1% per yr Decrease in Growth Rate	% Decline
Capital requirements (\$ billion)	559.2	457.4	18.2
Manpower requirements (1,000 man-years)			
Engineers	871.1	696.3	20.1
Craftsmen	3670.1	2942.2	19.8
Teamsters and Laborers	1271.4	1021.5	19.6

SCENARIO NO. 3: INCREASE IN POWER PLANT CAPACITY FACTORS

Description of the Scenario

The sensitivity of resource requirements to a change in power plant capacity factors is tested by increasing power plant capacity factors by 5 percent by 1985 and 10 percent by 1990, from their base case values (assumed constant through 1980) while holding total electricity production (kWh) equal to that of the base case. When compared to the base case, this has the effect of decreasing the required new generating capacity for major power plant types (coal, gas, oil, nuclear). The corresponding reductions in new capacity requirements are shown below for 1985:

- Coal - 24 GWe less than base case
- Nuclear - 14 GWe less than base case
- Oil - 5 GWe less than base case
- Gas - 4 GWe less than base case

Results and Analysis

Table 8-2 presents the ten-year (1976 to 1985) cumulative impacts on the selected capital and manpower resources for the construction of power plants only. Results are summarized below:

- Cumulative capital requirements decrease by \$32 billion
- Number of engineers (average annual) required decreases by 5,300
- Number of craftsmen (average annual) required decreases by 23,300
- Number of teamsters and laborers (average annual) required decreases by 4,100

Table 8-2

**SENSITIVITY OF SELECTED CONSTRUCTION CAPITAL AND
MANPOWER REQUIREMENTS TO POWER PLANT CAPACITY FACTORS**

Resource Requirements for Power Plants Only	1976-85 Cumulative		
	Base Case	5% Increase in Capacity Factor by 1985	% Change
Capital requirements (\$ billion)	208.3	176.3	-15.4
Manpower requirements (1,000 man-years)			
Engineers	343.9	291.0	-15.4
Craftsmen	1545.5	1312.8	-15.1
Teamsters and Laborers	323.9	283.4	-12.5

SCENARIO NO. 4: SHIFT FROM NUCLEAR POWER TO COAL-FIRED POWER

Description of the Scenario.

The sensitivity of resource requirements to a shift from nuclear to coal for electric power generation is tested by shifting to coal 100 GWe of the 1985 nuclear capacity in the President's program. In addition, coal picks up all subsequent new nuclear capacity specified in the base case for the period 1985-1995. The resulting capacities (GWe) are indicated below:

	<u>1973</u>	<u>1977</u>	<u>1980</u>	<u>1985</u>	<u>1990</u>
Base Case:					
Coal	165	210	267	312	400
Nuclear	21.3	65	90	204	400
Total Electric Capacity	427	526	657	899	1185
This Scenario:					
Coal	165	210	267	412	696
Nuclear	21.3	65	90	104	104
Total Electric Capacity	427	526	657	899	1185

Results and Analysis.

Table 8-3 presents the results for selected capital and manpower requirements. Selected results, compared with the base case, are summarized below:

- Cumulative capital requirements decrease by \$43 billion
- While cumulative requirements for total construction engineers decrease by 15 percent, nuclear engineering requirements decrease by 93 percent, and mining engineering requirements increase by 35 percent
- Cumulative requirements for construction manual labor decrease by 7 to 9 percent
- Requirements for total operations engineers and craftsmen are essentially identical
- Number of underground miners required to operate mines increases by 4,300 (average annual) and by 14,300 (peak annual, not shown)

Table 8-3

SENSITIVITY OF SELECTED CAPITAL AND MANPOWER REQUIREMENTS TO A SHIFT FROM NUCLEAR POWER TO COAL

Resource Requirements for Energy Supply and Transportation Facilities	1976-85 Cumulative		
	Base Case	100 GWe Shift from Nuclear to Coal in 1985	% Change
<u>Construction</u>			
Capital requirements (\$ billion)	559.2	516.7	-7.6
Manpower requirements (1,000 man-years)			
Engineers, all categories	871.1	738.3	-15.2
Nuclear engineers	11.4	0.8	-93.0
Mining Engineers	2.3	3.1	+34.8
Craftsmen	3,670.1	3,364.7	- 8.3
Teamsters and Laborers	1,271.4	1,179.3	- 7.2
<u>Operation and Maintenance</u>			
Engineers, all categories	793.6	793.1	- 0.1
Nuclear engineers	1.8	1.3	-27.8
Mining engineers	9.0	9.4	+ 4.4
Craftsmen	6,388.2	6,459.1	+ 1.1
Underground miners	683.1	726.6	+ 6.4
Equipment operators	405.2	415.2	+ 2.5*

* Percent change is attributed to coal mining equipment and transportation operators.

SCENARIO NO. 5: DECREASE IN GASOLINE CONSUMPTION

Description of the Base Case

The sensitivity of resource requirements to a decrease in gasoline consumption is tested by decreasing the 1985 consumption forecast for motor gasoline by one MMBPD, from 8.4 MMBPD, the level of consumption specified in the base case, to 7.4 MMBPD.

Results and Analysis

Table 8-4 presents selected results from this sensitivity run, which, when compared to the base case, are as follows:

- Construction requirements decrease by less than 1 percent
- Ten-year (1976 to 1985) cumulative capital cost requirements decrease by \$3.8 billion
- Number of construction engineers (average annual) required decreases by 390
- Number of construction craftsmen (average annual) required decreases by 2,140
- Number of construction teamsters and laborers (average annual) required decreases by 640

Table 8-4

SENSITIVITY OF SELECTED CONSTRUCTION CAPITAL AND MANPOWER REQUIREMENTS TO GASOLINE DEMAND

Resource Requirements for the Construction of Energy Supply and Transportation Facilities	1976-85 Cumulative		
	Base Case	1MMBPD Decrease in Gasoline Demand in 1985	% Change
Capital requirements (\$ billion)	559.2	555.4	-0.7
Manpower requirements (1,000 man-years)			
Engineers	871.1	867.2	-0.4
Craftsmen	3,670.1	3,648.7	-0.6
Teamsters and Laborers	1,271.4	1,265.0	-0.5

SCENARIO NO. 6: INCREASE IN OIL IMPORTS

Description of the Scenario

The sensitivity of domestic resource requirements to an increase in oil imports is tested by increasing the level of oil imports in 1985 by 1 MMBPD from 4.7 MMBPD, the level of imports in the base case, to 5.7 MMBPD. Of this total, imports of crude oil are increased by 0.6 MMBPD, imports of residual fuel oil by 0.3 MMBPD, and imports of distillate fuel oils by 0.1 MMBPD.

Results and Analysis

Table 8-5 presents the results for selected capital and manpower requirements for the construction and operation of energy supply and transportation facilities. Results are summarized below:

- Ten-year (1976 to 1985) cumulative costs decrease by \$6.9 billion
- Number of engineering jobs available (average annual, construction and operations) decreases by 960
- Number of craftsman jobs available (average annual, construction and operations) decreases by 4,340
- Number of total jobs available (average annual, construction and operations) decreases by 7,550

Table 8-5

SENSITIVITY OF CONSTRUCTION AND OPERATIONS RESOURCE REQUIREMENTS TO AN INCREASE IN OIL IMPORTS

Resource Requirements for Energy Supply and Transportation Facilities	1976-85 Cumulative		
	Base Case	1 MMBPD Increase in Oil Imports in 1985	Absolute Change
Construction			
Capital requirements (\$ billion)	559.2	552.3	-6.9
Manpower requirements (1,000 man-years)			
Engineers	871.1	866.4	-4.7
Craftsmen	3,670.1	3,645.2	-24.9
Operations and Maintenance			
Engineers	793.6	788.7	-4.9
Craftsmen	6,388.2	6,369.7	-18.5
Total Construction and Operations Manpower	17,281.0	17,205.5	-75.5

SCENARIO NO. 7: ACCELERATED WESTERN COAL DEVELOPMENT

Description of the Scenario

The sensitivity of resource requirements to an accelerated Western coal development is tested by increasing the supply of coal from Western sources from 210 MM tons, the production level in the base case, to 410 MM tons in 1985. (This is the amount of coal forecast from Western mines in the Coal Task Force Report to the FEA Project Independence Report, for the accelerated development case). The contribution from surface Western vs underground Western mines to this total is 93 percent surface, 7 percent underground, the same as for the base case. Because of the regional implications of this scenario, a regional run of the model was carried out. Based on information in the DEIS Report, all new surface mines added in the West are located in the Northern Rocky Mountains area, with 68 percent opened in Montana and Wyoming (Northern Mountain region of model) and 32 percent opened in North Dakota (West North Central region).

Results and Analysis

Table 8-6 presents aggregated results for selected facilities, capital and manpower requirements of this scenario. All results are based on regionally disaggregated analyses of facility and resource requirements. Compared to the base case, characteristics of the accelerated Western coal development scenario include the following:

- 32 more 6 MMT/Y surface Western coal mines are added
- 29 fewer 2 MMT/Y underground Eastern coal mines are added
- 13 fewer 4 MMT/Y surface Eastern coal mines are added
- 127 more new unit trains (100 cars, 3 locomotives) are required to transport the coal
- 30 fewer mining engineers (average annual) are needed
- 1,400 cubic yards less of dragline capacity need to be produced over the 1976 to 1985 period (construction only)

Table 8-6

SENSITIVITY OF FACILITIES, CAPITAL AND MANPOWER REQUIREMENTS TO ACCELERATED WESTERN COAL DEVELOPMENT

Facilities and Manpower Required	1976-85 Cumulative		
	Base Case	Accelerated Western Coal Development	Change in Number
Additional surface Western coal mines (6 MMT/Y)	19	51	+32
Additional underground Eastern coal mines (2 MMT/Y)	96	67	-29
Additional surface Eastern coal mines (4 MMT/Y)	51	38	-13
Additional unit trains (100 cars, 3 locomotives)	242	369	+127
Total mining engineers for construction and operation of energy facilities, (1,000 man-years)	11.3	11.0	-0.3
Additional dragline capacity (in 1,000 yd ³)	20.1	18.7	-1.4

The decrease in dragline capacity requirements is counter-intuitive, since 32 more surface Western mines (6 MMT/Y) are opened, while only 13 fewer surface Eastern mines (4 MMT/Y) are added. Hence, there is a rather large net increase in surface mining activity, and one might expect a corresponding net increase in dragline requirements. A closer check indicates, however, that "nominal" surface Eastern mines have much higher stripping ratios (i. e., overburden thickness to coal seam thickness) than surface Western mines, and accordingly, surface Eastern mines require more dragline capacity per ton of coal mined (by a factor of 6-to-1 on a per ton basis in the model data base).

While the overall impacts of accelerated Western coal development may not be large at the nationally-aggregated level, particular regional impacts might be quite significant. Table 8-7 shows the impact on selected manpower categories in the two regions where surface Western coal mines are added. Results indicate that:

- 10-year cumulative requirements for mining engineers increase by 76 percent in the Northern Mountain region and by 46 percent in the West North Central region
- 10-year cumulative requirements for equipment operators (operation only) increase by 16 percent in the Northern Mountain region and 31 percent in the West North Central region

Table 8-7

**SENSITIVITY OF SELECTED REGIONAL MANPOWER REQUIREMENTS
TO ACCELERATED WESTERN COAL DEVELOPMENT**

	1976-1985 Cumulative					
	Region 6			Region 8		
Resources Required for Energy Supply and Transportation Facilities	Base Case	Accelerated Western Coal	% Change	Base Case	Accelerated Western Coal	% Change
Construction and operations mining engineers (man-years)	285	501	75.8	987	1,439	45.8
Operations equipment operators (1,000 man-years)	15.7	18.2	15.9	19.7	25.8	30.8

Section 9

PRESENT USE AND FUTURE EXTENSIONS

PRESENT USE

Some possibilities for the present use of the model are demonstrated for specific cases in Section 7 and 8. Generally, the present use of the model is to provide the following categories of information. Given a normative fuel mix (both total energy demand level and fuels specification) for a future year, e.g. 1985 or 1990, the model produces the following outputs:

- An analysis of cumulative capital, manpower, and materials resource requirements
- The annual schedule for energy supply facilities and energy transportation facilities; annual schedules of the categories of resource requirements mentioned, which are associated with different schedules of development to supply the desired fuel mix in 1985 or 1990
- The regional requirements associated with the above

These basic information categories contained in the outputs can be useful in various aspects of future-oriented work, primarily in the generation, planning, and analysis of energy policy options. Some of these applications are discussed briefly in the following paragraphs.

Analysis of Total Requirements

Figure 9-1 is a schematic presentation of the Energy Supply Planning Model used as an integral part of a planning sequence that results in the generation of feasible energy programs.

In that sequence, the model appears in a loop where the implications of energy program proposals are tested for feasibility. The direct resource requirements resulting from the model are used to generate total (direct and indirect) requirements. (This can be done by various methods, including the use of input-output models.) The model is now being used in this manner in cooperation with the work at the Center for Advanced Computation at the University of Illinois.

Figure 9-1. A Modeling Sequence

Initiation of Availability Analyses

The model outputs may be used as a starting point for availability studies, either in the form of direct requirements for categories of equipment and materials (e.g. turbogenerators, draglines, rebar, etc.) or in the form of total requirements after the direct requirements have been used in input-output models to obtain the total industrial activity levels for given industries.

It is significant, of course, that the study of future availability of resources derived as requirements in the model be carried out in the same categories.

Impact Analysis

The information derived from the model may be used to initiate many kinds of impact analyses. Some impact categories are mentioned below:

- On selected industries (both energy industries and others, e.g. steel)
- On capital markets
- On labor
- Regional impacts
- Environmental impacts

FUTURE EXTENSIONS

Several extensions of the model are described below. The final criterion, however, lies invariably in the ability of a particular contemplated extension to meet an external need. It seems that the questions now confronting us point to modeling needs that address the following general topics:

- Long-range planning
- Global flows of energy (and other resources)
- Resource information at the regional (perhaps State) levels
- The relationship between the energy system and the economy
- The relationship between the energy system and life-styles
- Identification of constraints

Long-Range Planning

The need for longer range planning is apparent and has its underpinnings in the confrontation between growth and limited resources. It is anticipated that an aggregated model with the ability to simulate the energy system over longer periods will become useful in the near future.

Global Flows of Energy

An aggregated global supply planning model is seen as potentially useful for short-, intermediate-, and long-term applications.

Further Disaggregation to the State Level

Since the state boundaries constitute both a geographical and an institutional boundary, it may be significant to disaggregate the present model to the state level, particularly in order to explore the implication of various state-generated energy policy options.

Exploration of Energy-Economy Relationships

Consumption trends which held relatively steady for several decades, particularly in energy, are now rapidly changing. This factor and the relatively recent awareness of dwindling energy resources are

focusing attention on the need for a better understanding of the relationship among energy consumption, energy supply, and the economy. Since the model treats explicitly capital, labor, and materials requirements associated with various demand levels and growth patterns, coupling this model with models that simulate relevant social aspects will undoubtedly be useful in the future.

Further Disaggregation of Resources Categories

Energy industry totals for certain materials (e.g. aluminum, alloys) may be significant in determining potential constraints to development. The present level of disaggregation, or categories, may need modification.

In addition, it may become useful to provide a more elaborate interface procedure between the user and the model. One possibility is to provide the capability of allowing the user to specify policy options (e.g. the specification of preference in regional developments of coal) in terms of general criteria and to develop an interface scheme that will convert these by some heuristic method to the input variables used in the model.