TECHNOLOGICAL-ECONOMIC MODELS FOR ENERGY ANALYSIS*

by

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Paper presented at Institute of Gas Technology
Symposium on Energy Modeling and Net Energy Analysis
Colorado Springs, Colorado, August 21-25, 1978

* Research carried out under the auspices of the
Department of Energy under contract No. EY-76-C-02-0016.
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The United States has outlined the general objectives and guidelines that determine energy policy. In view of the many uncertainties about future events and circumstances that will affect the energy sector, energy policies must be flexible and adaptive as they evolve over the years ahead. The continuous analysis and assessment of the effectiveness of specific policies in the energy sector and of policies in other sectors of the economy that affect energy is required. At the governmental level, comprehensive analysis must be performed to compare alternative policy options and to ensure consistency among policies in other areas that will affect the supply and use of energy. Industries, whether suppliers or users of energy, may use analysis to aid in investment and operational decisions in a climate of significant technological and policy change. The energy system and economic models described in this paper are designed for general usage in government and industry.

Most energy policy issues and decisions involve a complex mix of technical, economic, environmental, and social value considerations. Specific policy actions addressing any one of these elements can have significant effects on the others, frequently in direct conflict with other policy objectives. Many of the important attributes of energy policy, such as resource requirements, demand, environmental effects, prices, and trade, are expressed in quantitative terms and are subject to known physical and economic relations. While most of these are relatively simple when taken individually, a comprehensive set of relationships must be assembled and integrated in order to capture the complexities of the entire scope of energy policy. The resultant system involves a blend of theory and practice from the scientific, engineering, and economic disciplines supported by the methods of applied mathematics, operations research, systems analysis, and computer science. The models described here are based primarily on engineering and economic relationships.

Another important set of policy considerations involve social, legal, and institutional factors that bear on value judgments and nontechnical, noneconomic constraints on energy policy. These factors are not easily quantified and thus are not incorporated in the models. Researchers have, from time to time, attempted to express these considerations in mathematical terms, but their techniques are neither proven nor generally accepted. Deliberate attention was given, however, in the
selection of the analytical techniques to provide the flexibility to incorporate judgmental constraints based on these nonquantifiable considerations and to make explicit and visible as much social and economic structure as possible to allow for value judgments on the part of decision-makers.

Among given policy questions, the relative role of quantitative and nonquantitative analysis may vary considerably. The quantitative methods described may provide between 10% and 90% of the information on which a decision is based, depending on the issue. In any case, the quantitative information is important and adds to the quality of the decision so long as the nonquantitative aspects of the issue are also dealt with.

The following sections describe the scope of energy system-economic analysis for which the models were developed, the content and structure of the various models and data bases, and some typical applications. The relationship of the methods used to alternative approaches is discussed in the concluding section along with recommendations for future work.

SCOPE OF ANALYSIS

The scope of energy policy analysis for which the energy system-economic models were developed is illustrated in Figure 1. This figure identifies the important components of policy and the issues that arise with respect to each; it does not identify the models employed. Indeed, some components are not dealt with directly by the models but require separate investigation and analysis outside of the models, e.g., the environmental and society-life-style components. Models and data bases are employed to analyze the economic sector, the technical system (in this case the energy system), the individual technologies that comprise the system, and the capital, labor, energy, and material resources on which the system is based. Several individual models and data bases are required to cover this full scope. They may be used individually or on policy questions that pertain to only one or two components of the system hierarchy, or in such combination as may be required for more complex issues.

The structure of the economy is represented using the Hudson-Jorgenson model. The economic model produces information on employment, GNP, and final consumption related to given technical and economic policies. This information, disaggregated to display the structure of energy services in terms of mobility (miles of travel by various modes), comfort (size and type of dwelling), and material consumption, as well as the market basket structure of GNP, is a partial representation of the kind of society and life-styles that come from the policy. The analysis of biomedical and environmental effects of the energy system and economic
activity provide another important part of the society and life-style picture. The social and environmental analyses are done outside of the models.

The energy system and technologies are modeled using a process or technological approach in which the efficiencies, cost, and environmental emissions of specific resources and technologies are described. The important information that the set of energy supply and utilization models provides is the price and availability of energy under specific technical policies and the environmental effects produced by the energy system. The technologies that may be employed for the supply and use of energy under different energy supply and price assumptions are also indicated by the process models.

It is well within the state-of-the-art of computing power to integrate all of the models employed to cover this complete hierarchy in one single model. Such an integration would increase the efficiency of the modeling activity, but would detract from the usefulness of the models in policy applications. Much of the insight into the important interrelationships and effects of policy comes from the setup and quantification of the model run, and from the careful interpretation of information passing between the models. Experience has shown that a human interface between models with minimal automation of the coupling is effective. This procedure also facilitates the insertion of constraints and adjustments based on nonquantitative considerations. At the same time, care must be exercised to ensure that such intervention is documented and is logical and reproducible.

ENERGY ANALYSIS

The methodology employed for energy analysis and technology assessment consists of three building blocks:

1. A network diagram portraying the technical structure of the energy system -- the Reference Energy System and Supporting Data Base.

2. A linear programming model to provide a technique for system design and synthesis -- the Energy System Optimization Model (BESOM and variants).

3. A set of process models that represents the technological options in major energy use sectors - residential and commercial space conditioning, steel, aluminum, paper, cement, and chemicals.

The Reference Energy System format and associated projection techniques are employed for developing energy supply-demand
projections at a high level of technological and functional disaggregation. The BESOM model provides a methodology for the detailed analysis of energy resource allocation and the energy technologies that may be employed under the influence of constraints on the availability of those resources and technologies. The usual objective in the optimization process is cost minimization; however, a variety of objectives and special constraints including environmental considerations and institutional factors may be reflected in the formulation of the model.

The coupling of the energy system optimization model with the Hudson-Jorgenson model of the economy overcomes certain difficulties in the conventional Input-Output approach by providing for technological change and interfuel substitution in the energy sector. This coupling also makes explicit the relationship between the energy demands used in the energy system model and the GNP structure represented in the final demand sector of the economic model. The effort to couple these models was a joint program between the National Center for Analysis of Energy Systems at Brookhaven and Dale Jorgenson Associates.

The scope of the energy system-economic model, their interrelationship with supporting data bases, and applications is illustrated in Figure 2. Following is a summary and definition of the elements shown in Figure 2.

**EMDB**

Energy Model Data Base.

A model independent data base including efficiency, air and water emission, and occupational hazard coefficients, expressed in appropriate units per $10^{12}$ Btu for approximately 600 supply processes and 200 end uses. Capital, labor, and material requirements developed by Bechtel Corporation may also be used with this data base.

**I-O**

Input-Output Model.

**ESNS**

Energy System Network Simulator. Energy flow computer program designed to produce resource and emissions inventory in RES format using data from EMDB.

**BESOM**

Brookhaven Energy System Optimization Model.

A linear programming model for analysis of optimal supply-demand configurations of the energy system. Alternative versions of the energy system model include DESOM, a time-phased LP developed by Marcuse (3); and RESOM, a nine-region single time-period version developed by Cherniavsky and Goettle.
RES - Reference Energy System.

Network description of energy system including all processes from extraction through conversion and transportation to end use. Resource consumption and emissions, and environmental effects inventories, are included.

Reference Energy System and Optimization Model.

The Reference Energy System (RES) and linear programming optimization model (BESOM) include a detailed representation of energy supply and utilizing technologies. These models were designed for application to the analysis of future development of the energy system and of fuel substitution patterns that may take place in response to constraints on the supply of individual fuels. A version of BESOM incorporating demand elasticities has been developed and will enhance the projection capability of the model by accounting for changes in the level of demand for energy in response to price changes.

The RES is essentially a specialized format for representing the detailed technological structure of the energy system along with resource consumption and emissions to air and water. As such, RES's can be developed with or without the aid of a simulation or optimization model. Computerized network-type flow models have been developed at Brookhaven to construct RESs drawing on efficiency, cost, and environmental data from the Energy Model Data Base (EMDB) (4). The EMDB is available on the Brookhaven computer and includes about 600 individual supply processes and 200 end uses.

The BESOM provides an optimization technique for use in the development of RESs reflecting supply constraints and their influence on interfuel substitution. The features of this model that are important in projecting energy supply and demand are the scope of the model in allowing for substitution between the electric and nonelectric sectors, the incorporation of a load-duration curve for the electric sector, and the inclusion of the utilizing devices as an important element in interfuel substitution. BESOM, at present, lacks regional detail which may affect fuel use patterns based on variations in transportation cost of different energy forms; however, a nine-region version, RESOM is now operational.

The RES and BESOM techniques require a special type of demand specification as input. The demand is specified as a Basic Energy Demand in Btu, which is the amount of energy required to support an energy utilizing activity such as space heat, automotive propulsion, etc., assuming that the energy could be used at 100 percent technical efficiency. The models
incorporate the efficiencies of supply and utilizing technologies and, thus, are employed to determine the resource demands, e.g., oil, gas, coal, electric, associated with the Basic Energy Demands that are specified as input.

The linear programming model of the United States energy system (5) includes provision for full range of interfuel substitution, including substitution between electric and non-electric energy forms. It encompasses the entire energy system including all resources and demand sectors as shown in the Reference Energy System, Figure 3. Since the range of interfuel substitutability that is feasible depends on the supply and utilization technologies that are available, the model includes the characteristics of these technologies. The technology related parameters that appear explicitly in the model are the efficiencies of energy conversion, delivery, and utilization devices; the emissions produced by the devices, and their cost. The intent in establishing the scope of the model was to include the technical elements that are of major importance in a framework that is as simple as possible. Simplicity is a requirement if all assumptions are to be evident, and the results easily interpreted.

The Reference Energy System may be quantified with a set of energy flows from alternate resources through the various energy conversion and delivery activities to specific end uses. Each link in the network represents a process or mix of processes used for a given activity, such as the refining of crude oil. Cost, efficiency, and emission coefficients may be associated with each link. The energy flows reflect the technical efficiencies of the individual processes and, thus, the flows decrease progressively through the network. The links shown in the network diagram reflect only existing technologies. Using the linear programming model, alternative energy flows may be determined which employ new technologies, and which also involve the substitution of domestic resources to replace imported oil and gas.

The model determines the optimal energy flows within the energy demand and resource supply constraints that are applied for a particular analysis. The output of the analysis includes the total annual cost of service, and an inventory of emissions to the environment associated with a given energy flow solution. Examination of the energy demand sectors at the right-hand side of the network indicates the degree of disaggregation included in the analysis. The substitution possibilities are dependent on these functional end uses and are quite different between the air-conditioning, automotive, and process heat categories, for example. The load-duration structure of electrical demands is also reflected in the model since the type of electric generating equipment employed is dependent on the portion of the
load curve that it is to operate on. This is an important consideration in substituting electric energy for other fuels in such categories as space heating and transportation where there are significant peak demands.

The optimization of the energy system is performed with respect to cost, and the objective is to minimize the cost of service, subject to policy, economic, and other constraints that may be represented in the objective function and constraint equations. Amortized capital costs, fuel costs, and other operating costs are included. A fixed charge rate of 15 percent is used for capital costs. Additional constraints are included to reflect existing systems that would not be replaced over the period covered by the analyses and to specify certain fuel uses that will probably occur for special reasons, such as regional variability, that are not reflected in an overall cost optimization of the United States energy system. Multi-objective analyses may be performed with the model. The alternative objective functions that are incorporated in the model include:

- annualized cost (with and without end-use devices)
- capital cost
- environmental index
- total resource use

Any one of these may be used as the objective function while the others are included as constraint equations. The usual procedure for multiobjective analysis is to first determine the global minimum for each objective with no constraints on the others and then determine the range of trade-offs that are feasible among the various objectives in order to arrive at a best compromise case.

The linear programming methodology is rich in economic interpretation. Of particular interest is the marginal value or "shadow price" of scarce resources in a given solution. These represent the unit change in overall cost of the system resulting from a unit change in availability of given resources. They are dependent on the cost differential between the scarce resource and a more costly, but abundant, substitute as well as on the relative technical efficiencies of the alternatives. The shadow prices provide a measure of the economic equilibrium of the system in terms of a comparison of the cost of expanding capacity of a given type with the value of that additional capacity. They may also be used to assess the structural changes in economic values assumed in a given analysis. The output for a given analysis also provides an extensive study of the range of cost and efficiency over which given technologies are competitive.
Economic Models

The economic models that are employed in combination with the energy system technological model include a fixed coefficient Input/Output model and the variable coefficient Hudson-Jorgenson Model. The Hudson-Jorgenson is employed as the basic macroeconomic and interindustry model that provides the economic impacts (GNP, employment, inflation, nonenergy prices, etc.) resulting from alternative energy policies and strategies.

The Hudson-Jorgenson Model of the economy is based on a system of accounts for the private domestic sector of the U.S. economy including final demand, primary inputs, and interindustry transactions. The system of accounts is represented in Figure 4. The energy conversion sectors and energy product sectors are modeled explicitly in BESOM but are implicit in the economic model. The resource to industry sector coefficients in the economic model are determined by BESOM.

The econometric model of nonenergy interindustry transactions includes a representation of producer behavior for each industrial sector included. This behavior is characterized by a system of technical coefficients that are determined as functions of prices of output and of primary and intermediate input. The coefficients are generated from the price possibility frontier giving the minimum price of output attainable for given input prices.

The econometric model also includes a model of consumer behavior that allocates personal consumption expenditures among the commodity groups in final demand.

The solution procedure of the econometric model is as follows: Starting with prices of primary inputs (capital, labor, and imports) and levels of productivity in the industrial sectors (with a projection of technological change), the prices of nonenergy products are determined. With this information and a set of energy prices and flows consistent with the fuel mix and energy scenario produced by BESOM, the matrix of technical coefficients is generated. Further, given the total personal consumption expenditures, prices of capital services, and import, the final demand sector may be calculated. This defines the total level of output for each of the sectors incorporated in the model. Finally, a complete system of interindustry account in current and constant prices can be generated along with the final demand structure.

A simplified diagram of the linkage between BESOM and the Hudson-Jorgenson Model is shown in Figure 5. The two models are solved independently but with the indicated information transferred between the two. The solutions are repeated until
convergence is obtained. At each step the fuel mix and prices from the energy sector model are inserted into the Hudson-Jorgenson Model while the demand for energy services determined by the economic model are inserted into BESOM.

The format of the interindustry accounts differs from the conventional input/output approach in that energy resources are assigned to specific energy conversion processes which deliver secondary energy forms (electric, gas, oil products, etc.) to energy product or service sectors (heat, motive power, etc.). These services in turn flow to the nonenergy industrial sectors. This differs substantially from the allocation of resources directly to the industrial sectors that is used in the environmental input/output models. This detailed allocation of resources through secondary energy forms to energy products is determined by the energy sector model that incorporates all feasible technological options. In this way, the forward-looking process detail in the technological model is used in an appropriate way to supplement the econometrically determined coefficients that determine the use of energy products in specific industries and the final demands for goods and services as governed by behavioral responses to price and income.

Following are the specific sectors included in the interindustry matrix when integrated with the energy model:

**Energy Resource Sectors**

1. Underground Coal  
2. Strip-Mined Coal  
3. Domestic Oil  
4. Shale Oil  
5. Imported Oil  
6. Domestic Natural Gas  
7. Imported Natural Gas  
8. Hydro Energy  
9. Nuclear Energy  
10. Geothermal Energy  
11. Solar Energy

**Secondary Energy Forms and Energy Product Sectors**

12. Base Load Miscellaneous Electric  
13. Intermediate Load Miscellaneous Electric  
14. Peak Load Miscellaneous Electric  
15. Storage and Synthetic Fuel  
16. Miscellaneous Thermal, Low Temperature  
17. Miscellaneous Thermal, Intermediate Temperature  
18. Miscellaneous Thermal, High Temperature  
19. Ore Reduction (Iron)  
20. Petrochemicals
21. Space Heat  
22. Air Conditioning  
23. Water Heat  
24. Air Transport  
25. Truck, Bus  
26. Rail  
27. Automobile

Industry Sectors
1. Agriculture, Nonfuel Mining, and Construction  
2. Manufacturing, Excluding Petroleum Refining  
3. Transportation  
4. Communications, Trade, and Services  
5. Coal Mining  
6. Crude Petroleum and Natural Gas  
7. Petroleum Refining  
8. Electric Utilities  
9. Gas Utilities

Primary Inputs
10. Imports  
11. Capital Services  
12. Labor Services

Final Demands
13. Personal Consumption Expenditures  
14. Gross Private Domestic Investment  
15. Government Purchases of Goods and Services  
16. Exports

The 110-sector fixed coefficient input/output model is employed as an accounting framework to assist in the specification of the energy service demands that are derived from the economic model and input to BESOM. The fixed coefficient model also provides a more detailed display of the interindustry transactions or production function that is adjusted to be consistent with the more aggregated coefficient in the Hudson-Jorgenson Model. This more detailed representation, while not necessarily unique, does serve the purpose of exhibiting a production function that may be subjected to engineering or process analysis to determine the technical feasibility of the processes implied in the Hudson-Jorgenson Model.

Environmental Analysis

The energy sector model incorporates a set of environmental coefficients that represent the air pollutants \( \text{CO}_2, \text{CO}, \text{SO}_2, \text{NO}_x, \) particulates, and aldehydes), water pollutants (acids, \( H_2SO_4 \),...
bases, BOD, etc.), land use, and occupational hazards per unit of energy delivered by particular plants and processes. Thus, for any energy-economic projection, a quantitative inventory of these environmental effects is provided. While such an inventory may fall far short of representing actual health effects, or even air and water quality, it does provide a measure of the overall burden placed on the atmosphere or water by particular strategies. Increased burdens corresponding to a strategy or policy may, of course, be offset by clever siting policies.

While somewhat unsatisfying, the simple inventory of emissions can be useful in environmental analysis. Regional inventories are, of course, more useful than national total and the multiregional energy model, RESOM, does provide emission inventories at the 9-census region level. Work is in progress in various biomedical and environmental programs on siting models that would locate energy facilities down to the country level and to relate regional emissions to health effects. When developed and qualified, these capabilities will be added to the technological-economic model.

**APPLICATIONS**

The levels of planning that have been defined in the literature are policy planning, strategic planning, and tactical or operational planning. Policy planning involves the formulation of goals or objectives and may be done with little regard to technology only when technical factors do not constrain the selection among alternative goals. Strategic planning concentrates on the development of a set of alternative paths to the desired goals and generally involves the establishment of criteria by which alternative strategies may be evaluated and ranked. Lastly, tactical planning deals with the determination of the steps necessary to implement a particular strategy.

In the area of energy systems where technical, economic and social factors are all interwoven, it is clear that technical factors do constrain policy alternatives and the policy planning must be tested by the development of options in strategic planning. The many constraints and effects that must be considered in defining alternate strategies influence the goals or objectives that are established. Thus, the goals and the strategies for attaining those goals are not independent. In this discussion no distinction will be made between policy planning and strategic planning.

The combined technological-economic models described here were developed in recognition of the constraints and influences of energy technology and resources in the development of the economy and society, particularly over the long term. The policy issues that may be addressed with the models is best described in terms of the socio-technical system hierarchy shown in Figure 1.
At the societal level it is recognized that national goals and life-style preferences are a prime determinant of the economic objectives and level of environmental protection. The specific objectives and constraints that are reflected in the technological-economic model to reflect national goals include:

- objectives for GNP growth and employment inserted into macroeconomic model

- structure of GNP (at 110-sector level described in input/output model) reflecting life-style preferences, e.g., fraction of income spent on specific goods and services

- constraints on emissions, or level of control of pollutants to air and water, placed on the energy sector model

- constraints on the use of specific resources applied to the energy sector model

Standard and regulatory policies adopted for consumers, industry, and the energy system may be reflected in the economic model and in the energy sector model in terms of:

- the efficiency and cost of energy conversion devices inserted into the energy sector model

- environmental limits and costs for emissions control in the energy system and in the overall economy

- prices and corresponding quantities of energy resources and fuels corresponding to regulatory policy

- capital requirements imposed on the energy sector to economy introduced into the economic model and/or energy sector model

Taxes and subsidies for energy conversion and utilizing technologies are incorporated as cost penalties or reductions in the cost-objective function of the energy sector model.

Research and development policies are reflected in the cost, efficiency, and availability of new energy supply and use technologies that are incorporated in the energy sector model. Taxes and subsidies as well as regulations and standards may also affect the cost and availabilities of the capital, labor, energy, and material resources that are employed in the energy system.

It is clear that a wide range of policy options may be introduced in quantitative terms into the combined technological-
economic model. The modeling framework provides for the assessment of the technical, economic, environmental, and social consequences of the policy. Some policy options, such as price regulation of natural gas, enter into the analysis in a simple way through the adjustment of the price used in the energy model objective function and the corresponding quantity constraint as may be determined from a model of gas exploration and production. Although the insertion of the policy is simple, the consequences analyzed include the substitution of other resources to make up any unsatisfied demand, the environmental effects of the use of gas and substitutes, and the economic impact of the departure from free market equilibrium prices.

Other policies may enter in a more complex way with equally complex effects. An environmental protection policy, for example, might involve constraint on the use of specific fuel forms, subsidies to other fuels, as well as overall constraints on emissions corresponding to nondegradation criteria.

Following are some specific examples of policy applications that have been completed using the technological-economic models, either individually or in combination.

1. Effect of Btu Tax on Energy Consumption and Economic Growth. This analysis was performed for the Ford Foundation Energy Policy Project (6) using the Hudson-Jorgenson Model alone. The results indicated significant flexibility in the energy/GNP relationship over the long term when there is sufficient time to change the capital stock.

2. Assessment of Energy Technologies. The Reference Energy System has been employed as an assessment technique for alternative energy technologies for the Office of Science and Technology in 1972 (7), the Atomic Energy Commission in 1974 (8), and the Energy Research and Development Administration in 1975 (9). In all of the assessments of energy R&D priorities, projections of baseline Reference Energy Systems were first established for future years. Then individual technologies were inserted and the resource, environmental, and cost changes resulting from the employment of that technology were calculated. This information was used as one element of the basis of R&D priorities. Other factors considered separately by the policy makers were the cost of the R&D, the probability of success, and the need for federal involvement.

3. Cost/Benefit Analysis of New Energy Technologies. These studies were performed using the single time period energy system optimization model, BESOM, applied for several future years. The discounted stream of economic benefits resulting from the implementation of individual technologies were calculated and compared with the present value of the projected R&D costs.
A similar study was performed for the National Academy of Science Committee on Nuclear and Alternative Energy Systems using the time-phased optimization model, DESOM.

4. Calculation of Benefits of Energy R&D. The first application of the combined technological-economic model was performed for ERDA in 1976 (10, 11). In this study two policies were examined, each leading to attainment of a specific reduced level of oil imports by the year 2000. One policy involved a Btu tax only to attain the goal, while the other involved a research and development effort to develop new energy sources and more efficient systems coupled with a Btu tax of lower magnitude than in the first policy. The results indicated that the discounted long-term economic benefits of the R&D policy compared with the tax-only policy were well in excess of the projected R&D costs.

5. Projections of Future Energy Requirements. These studies have been performed using the combined technological-economic model. Projections, conditioned upon the input assumptions of population, productivity, and resource availability produce a consistent picture of energy, environmental, and economic relationships.

FUTURE WORK

Work is now in progress to improve certain features of the technological-economic models. This effort involves many workers at Brookhaven National Laboratories, Dale Jorgenson Associates Inc., and cooperating university and industry groups. Among the improvements that are now in progress are:

1. Further definition of end-use technologies and systems including representation of the current capital stock. This work is central to studies of energy conservation and fuel switching.

2. Incorporation of energy resource supply models into the structure.

3. Regionalization of energy sector model for purposes of environmental analysis.

4. Estimation of environmental damage functions.

5. Procedures for the explicit treatment of uncertainty in the energy sector model.
REFERENCES


Figure 1  POLICY CONSIDERATIONS

Socio-technical system hierarchy

- Society and lifestyles
  - Biomedical and environmental effects
  - Economy
  - Technical system
    - Technology
      - Resources
        - Energy
        - Material
        - Capital
        - Labor
      - Policy areas
        - National goals
        - Standards
        - Regulation
        - R&D
        - Tax & subsidy
        - Standards
        - Tax and subsidy
        - Regulation
        - Standards
FIGURE 2 - ENERGY SYSTEM-ECONOMIC MODELS AND SUPPORTING SYSTEMS

DATA SOURCES
- EMDB (BNL AND BECHTEL)
  - EFFICIENCIES
  - EMISSIONS & EXTERNALITIES
  - CAPITAL & OPERATING COST
  - MATERIALS
  - LABOR

MODELS
- FLOW MODELS
  - ESNS
  - ESYG

ENERGY SYSTEM REPRESENTATION
- OPTIMIZATION
  - BESOM
    - STATIC
    - DYNAMIC

APPLICATIONS
- TECHNOLOGY ASSESSMENT
- SUPPLY-DEMAND PROJECTIONS
- INTERFUEL SUBSTITUTION

DEMAND
- FACTOR PRICES
- ENERGY PRICES

ECONOMY
- INPUT-OUTPUT
- MACROECONOMIC AND INTERINDUSTRY MODEL

APPLICATIONS
- ENERGY-ECONOMIC RELATIONS
- ENERGY/GNP
- LIFESTYLES

I-O COEFFICIENTS
- ENERGY INPUTS
- INDUSTRY INPUTS TO ENERGY SYSTEM
- CAPITAL COEFFICIENTS
- OTHER

RESOURCE & DEMAND ACTIVITY ESTIMATES
- COMMERCIALIZATION AND IMPLEMENTATION ESTIMATES
Figure 3  REFERENCE ENERGY SYSTEM

<table>
<thead>
<tr>
<th>RESOURCE EXTRACTION</th>
<th>REFINING AND CONVERSION</th>
<th>TRANSPORT</th>
<th>CONVERSION</th>
<th>TRANSMISSION AND DISTRIBUTION</th>
<th>UTILIZING DEVICE</th>
<th>END USE</th>
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NOTES:
1. FLOWS IN $10^{16}$ Btu
2. SOLID LINE INDICATES REAL PROCESS
3. CONVERSION EFFICIENCIES SHOWN IN PARENTHESES

TOTAL ENERGY, 1972
72.2

AVAILABLE ENERGY, 1972
53.3

 batt

MISC. ELECTRIC
ALUMINUM
IRON & STEEL

(Air Conditioning)
SPACE & WATER HEAT

(THERMAL)

(Petroschemicals)
AUTOMOBILE

(BUS, TRUCK, RAIL & SHIP)

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS  INC.
Figure 4  INTERINDUSTRY TRANSACTIONS IN THE INTEGRATED MODEL

INPUT TO SECTORS:

ENERGY RESOURCE SECTORS
ENERGY CONVERSION PROCESSES
ENERGY PRODUCT SECTORS
NON-ENERGY INDUSTRY SECTORS

INTERINDUSTRY TRANSACTIONS

PRIMARY INPUTS

TOTAL INPUTS

FINAL DEMANDS

TOTAL OUTPUTS
Figure 5 COUPLING OF ECONOMIC AND ENERGY SECTOR MODEL

MACRO-ECONOMIC AND INTER-INDUSTRY MODEL

resources and technologies used, price of service or product, environmental effects
demand for product or services

TECHNOLOGICAL MODEL

Reflects changes in final demand, GNP, employment, etc. in response to economic and technical policies, resource availability, and technological change.

Given set of alternative technologies, determines optimal use of resources and technologies with respect to specific objectives, constraints, and requirements. Indicates environmental effects.