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Regional energy modeling: An evaluation of alternative approaches

MASTER

Regional Studies Program

Energy/environmental assessments

Argonne National Laboratory

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REGIONAL STUDIES PROGRAM

title

REGIONAL ENERGY MODELING:
AN EVALUATION OF ALTERNATIVE APPROACHES

by

Alan S. Cohen and Kenneth W. Costello

Energy and Environmental Systems Division

Contributors

Gilbert N. Bassett*
Ronald C. Bruno**
Alfred Kahn**
Ho Tak Kim***
Stanford L. Levin**
David I. Steinberg**
Charles A. Thornton**

June 1975

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- * University of Illinois at Chicago Circle
- ** Southern Illinois University at Edwardsville
- ***Energy and Environmental Systems Division, ANL

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EXECUTIVE SUMMARY

The Regional Studies Program being conducted by the national laboratories of the Energy Research and Development Administration (ERDA) seeks to devise and apply a framework and associated data base for analyzing regional impacts of energy development programs and policies. Argonne National Laboratory is currently responsible for conducting regional analyses in geographic areas such as the Northern Great Plain, the Midwest and the southwestern states of Arizona and New Mexico and for synthesizing into a national assessment of coal technologies, the coal-related studies being conducted by the other national laboratories. ANL's regional energy budget effort, a part of the Regional Studies Program, is to develop the modeling techniques needed to predict regional energy supply/demand options. ERDA's Division of Biomedical and Environmental Research (DBER), as the sponsor of the Regional Studies Program, is primarily interested in the regional health, environmental and socioeconomic impacts of the energy supply/demand options.

Since the philosophy of the regional energy budget analysis is to build upon, rather than to duplicate, the work of others, Argonne evaluated several existing energy models, all of which consider more than one fuel and economic sector. Their capabilities were judged in comparison to those of a comprehensive and logically consistent regional energy model. The authors of the report recommend some of the models for use in the Regional Studies Program and suggest a direction for future energy model development because of certain shortcomings found in all the models.

The models examined were the Battelle Columbus-EPA Energy Quality Model, Baughman's Dynamic Energy System Model, the Brookhaven National Laboratory Energy Models, the Energy Management Simulation and Analysis System, the Hudson-Jorgenson Energy Model, Kalter's Parametric Models of Fossil Fuel Markets, the Project Independence Evaluation System, and the Wisconsin Energy Model.

The criteria used to evaluate the models can be divided into three categories:

- Model comprehensiveness, which included spatial, energy supply, and energy demand details,
- Economic aspects of the model, which included the determinants of total supply and demand, interfuel competition, and interregional competition, and
- Model capabilities, which included the ability to simulate the effects of both policy and technology changes.

Features of the various models are summarized in Tables 1 and 2.

Construction of a single comprehensive energy model is not recommended. The potential benefits of such a model very likely would be outweighed by its cost, short-lived usefulness, economic inefficiency, and difficult-to-interpret results. Argonne does recommend, however, that a library of techniques be developed and maintained, to enable analysts to select models that best fit their needs and to avoid excessive data collection, computer, and analytic costs. For the Regional Studies Program, this library should include two types of models: "local impact" and "national synthesis" models.

Local impact models would simulate consequences of energy policies at the state and substate levels. The Wisconsin Energy Model (WISE) should be added to the Argonne energy system simulation library and modified somewhat for use as a local impact model. The Battelle-EPA Energy Quality Model also should be acquired because of its particular usefulness in evaluating the effect of alternative sulfur dioxide regulations on power plants throughout the country.

National synthesis models would estimate energy supplies and demands as functions of decisions that affect the national energy market. Of these, the Project Independence Evaluation System (PIES) is recommended as the national synthesis model to be added to the Argonne library.

The two types of models can be used in conjunction with one another as required by the problem being analyzed. A national synthesis model can provide regional energy supply and demand estimates consistent with national policies, and this output can be used in turn as input for a local impact model. Similarly, if a regional policy is expected to affect the national energy market, a local impact model's output can become input for a national synthesis model.

Table 1. Summary of Economic Aspects of Energy Models

MODELS	ENERGY DEMAND	ENERGY SUPPLY	INTERFUEL COMPETITION				INTERREGIONAL COMPETITION	
			Method	Market Lags (Dynamics)	Sectors	Fuel Prices	Method	Transportation Cost
Battelle Columbus - EPA Energy Quality Model	NPC's forecast for U.S. AQCR forecast taken from 1973 study by M.C. Cook Sartorius and Company Other exogenous sources	Stepwise supply function applying the "minimum acceptable selling price" concept No exploration	Linear Programming	Power Plants constrained to present fuel use capabilities	Electric Utilities	Minimum acceptable selling prices are provided exogenously and adjusted upward based on shadow prices obtained from LP mode.	Linear programming (Objective function minimizing total systems energy costs)	Rates provided exogenously
Baughman's Dynamic Energy System Model	Demand by sector provided exogenously	Parametric engineering supply functions Exploration activity provided exogenously	Log linear equation which is price sensitive (Partly econometric and parametric)	Total demand assumes that some consumers are "locked in" to particular fuel, i.e., demand for fuel is not price sensitive Supply model assumes exponentiated delay functions	Electric Utilities Residential/ Commercial Industrial	Equals point on supply curve corresponding to a given demand for each fuel	Not considered	Assumes that costs are constant multiples of supply prices of each fuel
Brookhaven NL Models ● Basic	Exogenously provided from other studies, extrapolation, or user's assumption	Exogenously provided from other studies	None	Not considered	Not considered	Exogenous	Not considered	Rates taken from FPC 1970 National Power Survey Report
● Modified	Same as above	Exogenously provided elasticity of supply (presently set at .5)	Linear Programming	Assumes no fuel conversion until capital stock has reached a given age	By functional activities (end-use) of Residential/Industrial Electrical Utilities	Derived from exogenously provided supply functions and shadow prices of LP model	Not considered	Rates taken from FPC 1970 National Power Survey Report
Energy Management Simulation and Analysis System (EMSAS)	Based on trends or exogenously provided (for industrial sector, it can be estimated using price sensitive econometric equations)	Parametric engineering - simulation equations (oil, natural gas) Exogenous (coal) Exploration is price-sensitive, probability of success based on historical trends	Trend analysis Econometric Market share equation (Varies by sector)	Portion of demand is assumed to be market sensitive This portion is provided exogenously Gas and oil supply models allow for lag between time when they are committed to production	Industrial Residential (single unit homes) Electric Utilities	Future prices trended or provided exogenously	User determines inter-regional flow of energy	Rates provided exogenously
Hudson - Orgenson Model (H-J)	Input-Output and Macro Growth Model (technical coefficients and final demand components estimated by econometric equations)	Exogenously provided from other studies I/O coefficients	Econometric equations	Macroeconomic model is dynamic Comparative statics	Agriculture, manufacturing, transportation, communications, coal mining, crude petroleum and natural gas, petroleum refining, electric utility, and gas utility as intermediate demand, and residential, government, and commercial as final demands	Market clearing prices dependent upon demand and supply conditions	Not considered	Not considered
Kalter's Parametric Model	Dynamic parametric equation	Dynamic parametric equation	Parametric equation (substitution occurs if fuel prices differ by fixed percentage)	Assumes short-run and long-run elasticities for demand and supply (with response rate)	All sectors simultaneously	Market clearing prices dependent upon demand and supply conditions	Not considered	Not considered
Project Independence Evaluation System (PIES)	Econometric equations	Modified NPC parametric equations used to calculate the "minimum acceptable selling price" by the discounted cash flow technique (oil, natural gas) Step function where price is the "average minimum acceptable selling price" (coal) Exploration activity for natural gas and oil is provided exogenously	Market share equation (linear logit) Linear Programming	Econometric demand models developed with long-run and short-run elasticities	Residential/Commercial Industrial (Market Share) Electric Utilities (Linear Programming)	Equals market clearing price where demand equals supply	Linear Programming (objective function: minimizing total systems energy costs)	Rates provided exogenously or determined by Task Force
Wisconsin Energy Model (WISE)	Trend analysis Engineering, parametric models User defined	Exogenous	Assumed change in energy intensiveness coefficients (Industrial) Assumed mixes of fuel (Electric Utilities)	Explicit consideration of age of capital equipment	Industrial Electric Utilities	Published prices from various sources	Not considered	Not considered

Table 2. Summary of Energy Model Comprehensiveness and Capabilities

MODELS	SPATIAL	SUPPLY	DEMAND	POLICY		TECHNOLOGY	
	Level	Fuels	Sectors	Type	Independent Variables Affected	Type	Independent Variables Affected
Battelle Columbus - EPA Energy Quality Model	92 Supply districts of fuels 233 AQCR demand region	4 grades of coal by sulfur content Natural gas Distillate and residual oil	Residential/Commercial/ Industrial Electric Utilities	SO ₂ regulations	Supply availability Control costs	Power plant SO ₂ Controls Fuel production technology improvements	Control costs Fuel prices
Baughman's Dynamic Energy System Model	U.S.	Coal Natural gas Oil Nuclear Hydro	Residential / Commercial Industrial Transportation Electric Utilities	Directly affecting price (e.g., tax, tariff)	Price	Directly affecting price	Price
Brookhaven NL Models ● Basic	U.S. N.Y. City	Coal Natural gas Oil (distillate, residual, jet-fuel, gasoline) Nuclear Hydro	Residential Commercial Industrial Transportation (by end-uses) Electric Utilities	Parametric reduction of appliance or boiler efficiencies	Efficiencies	Parametric changes	Technology Trajectories
● Modified	U.S.	Same as above	Same as above	Environmental regulation Directly affecting price	Constraints Price	Directly affecting cost	Price
Energy Management Simulation and Analysis System (EMSAS)	State (Industrial demand) Census Region demand Supply estimates on national basis which are allocated to "fuel districts"	Coal (only utility usage) Natural gas Oil Nuclear Hydro	Residential/Commercial Industrial (2-digit SIC) Electric Utilities Natural gas feed stocks	SO ₂ regulation Directly affecting price (e.g., tax, tariff)	Price Control Costs	Directly affecting price Sulfur control technology	Price Costs
Hudson - Jorgenson Model (H-J)	U.S.	Coal Natural gas Petroleum Nuclear Hydro	9 intermediate sectors Personal consumption Government Investment Exports	Directly affecting price (e.g., tax, tariff) Directly affecting macroeconomic variables	Energy price Real income	Directly affecting price	Price Productivity Real income
Kalter's Parametric Model	U.S.	Coal Natural gas Oil	All sectors simultaneously	Directly affecting price (e.g., tax, tariff)	Price	Directly affecting price	Price
Project Independence Evaluation System (PIES)	U.S. and Census Region Demand Supply districts of fuels	Coal Natural gas Oil Nuclear Hydro Synthetic fuels, Solar and Geothermal	Residential/Commercial Industrial (2-digit SIC) Transportation Electric Utilities (some end-uses)	Directly affecting price (e.g., tax, tariff)	Price	Directly affecting price	Price
Wisconsin Energy Model (WISE)	State of Wisconsin	Coal Natural gas Oil (distillate residual, kerosene, LPG, gasoline) Nuclear Hydro	Residential Commercial Industrial (2-digit SIC) Transportation Electric Utilities Agriculture (by end-uses)	Parametric change in engineering efficiency Regulations such as building codes	Energy intensive uses coefficients	Changes in engineering efficiency	Engineering parameters used in demand sub-models

Based upon this review, Argonne has concluded that none of the models can adequately predict and analyze regional effects of national energy policies and programs. All were found deficient in two major respects: they did not consider interregional competition and they did not integrate energy supply and demand forecasts with economic growth.

Because of these two serious deficiencies found in existing models, this report recommends a systems simulation approach for developing a new multiregional energy supply and demand model. This model would incorporate all the strengths of the existing models and would also simulate interregional competition and make the energy system part of the entire economic system.

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REGIONAL ENERGY MODELING:
AN EVALUATION OF ALTERNATIVE APPROACHES

by

Alan S. Cohen and Kenneth W. Costello

ABSTRACT

Eight comprehensive energy models, representing the current state of the art, are evaluated and their ability to analyze present energy issues is discussed. Initially, we define the criteria on which the evaluations are based and, in the process, we generate a conceptual model that contains the essential characteristics of a regional energy model. The criteria are disaggregated into three components: model comprehensiveness, economic aspects, and model capabilities. Each of the models are evaluated individually and the modeling techniques used are compared.

The models are categorized into "local impact" and "national synthesis" groups. The local impact group can be applied to state or substate areas. Their forte is the degree of the end-use detail they provide. One of their shortcomings is the inability to analyze the regional impact of national energy policies. The "national synthesis" models are designed to analyze the impacts of national policies on the availability and/or consumption of energy on a national or regional basis.

We conclude that none of the models evaluated satisfy all of the criteria defined for energy models. The more important shortcomings are the inadequate consideration of the competition between production and/or consumption regions, and the lack of integration of the energy economic systems with the rest of the economy. Recommendations for future research and model development are presented. The primary goal of these future research efforts is to alleviate the shortcomings of existing techniques.

1. OBJECTIVES OF THE REGIONAL ENERGY
BUDGET MODEL ANALYSIS

The effects of government and private sector energy policies are varied and interrelated. Before implementing research and development programs, new technologies, environmental and price regulations, import quotas, and other energy-related policies,* the consequences of these programs must be identified and quantified on a regional basis. To evaluate the regional impacts of energy

* In this report "energy policy" is often used in a broad sense that includes technology advances and R&D programs.

policies, we need to consider the location of reserves, production and transportation costs, as well as the demands for energy and nonenergy goods. Developing techniques for analyzing these factors is the objective of the Regional Energy Budget activity at Argonne National Laboratory. The end result of this program will be a modeling capability for assessing the impacts of energy-related policies.

The first task in reaching this goal is an evaluation of existing models developed for similar projects. Only those models that consider more than one fuel and sector (e.g. utility and residential) are reviewed. Most of these energy models have been formulated for use on a national level. Because of differing energy markets within various regions of the country, these national models may be inappropriate for assessing regional energy-policy impacts. Regional models may also be designed inadequately if they do not account for interregional transactions of energy-related goods. Existing energy models are evaluated to identify their strong and weak points and the issues they address.

A framework for evaluating current models is presented in the next section. It identifies features that should be included in a comprehensive and logically consistent regional energy model. In Section 3, eight energy models are evaluated using the criteria discussed in Section 2. A preliminary review of each model was sent to respective authors or users for comment. Where appropriate these comments are presented in Appendix A. These models are compared and a summary of their strengths and shortcomings are presented in Section 4. The analytical techniques incorporated in each model are described and areas for future research are identified. Recommendations for use and adaptation of these techniques are presented in Section 5.

The report contains three appendixes. Appendix A, as stated, provides comments on our critiques received from developers or users of the models. Appendix B is a review of Herendeen's energy input/output matrix, and Appendix C is a reprint of testimony given by four MIT professors on their evaluation of the PIES model.

2. FRAMEWORK FOR EVALUATING REGIONAL ENERGY MODELS

An evaluation of energy models cannot be conducted without first defining the criteria on which the evaluation is based. Three sets of criteria are used: model comprehensiveness, economic aspects of the model, and model capabilities. The model comprehensiveness section defines the scope of the model in terms of the spatial, energy-supply, and energy-demand details. The economic aspects of the model considered are the determinants of total demand and supply, interfuel competition, and interregional competition. A model's ability to simulate the effects of policy or technology changes are considered in the capability section. These three sets of criteria, therefore, define the eight characteristics used to evaluate each model. These criteria are listed in Table 2.1. In this section, the criteria used and the reasons why these model characteristics are considered desirable are presented. To aid in the discussion of the importance of these criteria, a schematic of an energy model is provided in Fig. 2.1.

Table 2.1. Criteria for Evaluating Energy Models

Criteria	Examples
Comprehensiveness	
Spatial detail	States, census regions, nation
Supply sector detail	Coal, oil, natural gas, high and low sulfur fuels
Demand sector detail	Industrial, transportation, lighting, space heating
Economic Aspects	
Total demand and supply determinants	GNP, income, energy prices, reserves
Interfuel competition	
Interregional competition	
Capabilities	
Policy actions	Import quotas, environmental regulations, conservation
Technology changes	Solar energy, coal gasification, electric cars

Fig. 2.1. Regional Energy Budget System

The first set of criteria (model comprehensiveness) is important because the models will be ultimately used to assess the regional and sectoral impacts of policy and technology changes on energy production and consumption. Without adequate detail in the model, these separate effects cannot be evaluated. Furthermore, the impacts estimated with a highly aggregated model may err significantly because they do not account for variations in regional and sectoral markets.

The minimum level of spatial detail is not easily defined since it depends in part on the policy under consideration. For example, the environmental impacts of alternative energy consumption patterns may be highly localized within a particular state. In this situation even state-level analysis may be insufficient. On the other hand, some technology changes or federal policy actions may only have significant regional impacts at the "Census Region" level of aggregation. Because of the importance of spatial detail in many analyses and the varying levels of detail required, and because it is generally easier and more accurate to aggregate data, a model that has greater than a Census Region level of detail is desired.

Because there are practical cost and data limitations, a model that considers coal, oil, and natural gas as primary fuels, and electricity as a secondary energy source, is considered to have adequate supply detail. Without at least this level of detail, interfuel competition cannot be modeled. On the demand side, a model should include industrial, residential, commercial, and transportation demands. The industrial sector should include manufacturing, agricultural, and utility energy demands. These levels of detail are viewed as minimum requirements for a comprehensive energy model.

Since most energy-related policy actions or technology changes affect the energy market, an energy model should adequately simulate market behavior. The demand for nonenergy goods affects energy demands in two ways: (1) the demand for energy is in part a derived demand resulting from the use of energy as an input in the production of goods and services; and (2) energy and nonenergy goods compete against each other; i.e., given a fixed budget, the more people spend on energy, the less they will be able to spend on nonenergy goods.

Because economic prosperity is strongly related to energy prices, an energy model should reflect this relationship. That is, the model should

consider the feedback effect of energy prices on the demand for goods and services (as shown in Fig. 2.1). Energy prices also affect levels of exploration, the economic feasibility of alternative production processes, and ultimately the supply of energy. These relationships should be explicitly accounted for in a comprehensive energy model.

Given the total demand and supply of energy, market shares of each fuel must be determined. Market shares are a function of relative fuel prices, stocks of capital goods, consumer preferences, and other variables that affect interfuel competition. Because the availability of fuels at a given market price varies significantly between regions of the country, the interfuel competition aspects of the model may be meaningful only if the model is regionalized. To emphasize this point, the interfuel competition aspect of the schematic model in Fig. 2.1 is labeled as a regional energy market.

Interfuel competition is an essential part of any model used to analyze the impacts of oil import quotas, sulfur dioxide control regulations, strip mine reclamation regulations, deregulation of natural gas prices, coal gasification technology advances, and other perturbations of the energy market that will affect the price of some fuels more than others. A model that does not take into account market adjustments resulting from these policies may estimate incorrectly their relative advantages or disadvantages.

Equally important to interfuel competition is interregional competition. Differences between regions include costs of production, quality of fuels, and proximity to markets. Production costs may be different because of the type of mining used (strip vs. deep mine) or the depth or level of depletion of the reserve. Varying production costs affect the prices suppliers are willing to accept for their products. The quality of the fuel (the heat values and sulfur and ash contents of the fuels in particular) is important when environmental regulations are being considered. Because of environmental regulations, some sources of energy cannot be used without expensive control equipment, the net effect being an increase in the cost of using those sources of energy. Proximity to markets has been a major factor in regional differences in fuel consumption patterns. In some instances, transportation costs represent the major portion of the selling price of a fuel. For these reasons, any model that does not consider interregional competition cannot, for example, estimate adequately the advantages of locating a coal gasification plant in North Dakota rather than Southern Illinois.

To be capable of simulating interregional competition the model must consider all competing regions, hence a national or state model would clearly be inadequate for this purpose.

The third set of criteria, model capabilities, deals with the problems to which the models can be applied. Policy options, which consist of regulatory, funding, and priority-setting decisions, as well as technology advances, will affect energy supplies and demands and thus the price that must be paid for energy. In this analysis, a model that does not endogenously simulate the effects of policy or technology changes is classified as one that does not have this capability. Some models can simulate the energy impacts of changes in the economy if the resulting price, cost, demand, GNP, etc. changes are provided exogenously. Such models are easily adapted for policy analysis if auxiliary programs are constructed to simulate the impacts of the policy on these independent variables. Finally, some models may have restrictive assumptions that preclude their use for policy analysis.

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3. EVALUATION OF EXISTING ENERGY MODELS

3.1 BATTELLE COLUMBUS-EPA ENERGY QUALITY MODEL

"The Battelle-EPA energy quality model is a large linear program that determines a minimum national cost distribution of coal, natural gas, residual oil, distillate oil, and nuclear power in the contiguous United States under specified conditions of supply, price, and demand."¹ The model was developed at Battelle-Columbus over a three-year period. The work was sponsored by the Office of Air Programs of the U.S. Environmental Protection Agency. This review is based on the description of the model by Chilton and Jimison.²

Because the research was directed toward estimating the impact of sulfur dioxide regulations on fuel availability and prices, the model has inherent strengths and weaknesses for adaptation to the regional studies program. These are to be discussed in greater detail later in this section.

Output of the model is comprised of: (1) a fuel-policy schedule for each grade of fuel in each region, (2) a fuel-use schedule (including nuclear) showing the amount of each grade of fuel in each region; (3) a supply schedule showing the amount of each grade of fuel shipped from each supply district to each use region, and (4) a control schedule showing the degree to which each region uses stack-gas controls and/or low-sulfur fuels. These outputs, particularly the first three, are exactly the parameters desired for the regional studies program. The remainder of this review discusses the methods and the level of detail used to estimate these parameters. A schematic of the model is provided in Fig. 3.1.

3.1.1 Model Comprehensiveness

The comprehensiveness of the model is evaluated relative to the types of energy sources considered, the types of demand sectors considered, the spatial extent of the model, the levels of analysis (e.g., extraction, transportation), and the flexibility of the model for adaptation and expansion.

Estimates are provided for coal, residual oil, distillate oil, natural gas, and electricity (including nuclear). Furthermore, these fuels are classified by their sulfur content. For example, coal may be classified into three categories of high-, medium-, and low-sulfur coals. Presently,

Fig. 3.1. EPA Energy Quality Model

the model handles ten fuel types representing combinations of basic fuels and their characteristics. Conceptually, there doesn't seem to be any problem of extending these to include other energy types and characteristics. Practically, there may be limits based on data availability or computational efficiency.

The demand for energy is quite aggregated. The most detail is provided for power plants. Their demand for basic energy is determined on the basis of estimated demand for electricity, the efficiencies of electric energy generation, the relative prices of fuels, and environmental controls. Energy demands for residential, commercial, and industrial users are aggregated into a single demand sector. Transportation energy demands are not included in the model. The lack of detail or omission of the nonpower plant energy sectors could severely limit the potential use of the model. However, the Battelle Fuels and Energy Economic group feels that the model can be extended to include greater industrial detail (2-digit SIC level) and include the transportation sector.³

The most appealing feature of the Battelle-EPA model is its spatial detail. The model can consider each of the 238 air quality control regions (AQCR) in the continental United States as an energy demand region. Actually, the AQCR designation is not an integral part of the model since the user has the option of grouping counties in a number of alternative ways. The model also incorporates a distinct set of fuel supply districts for each type of fuel. Presently, 23 coal, 38 oil, and 31 natural gas supply districts, which represent unique geographic areas, have been identified. No geographic representation for nuclear power plants was used. Furthermore, nuclear fuel districts are not included.

Each demand region and supply district is designated by an x-y coordinate at its centroid and the crow-flight distance between them is used to estimate transportation costs. For reasons of computational efficiency, all of these demand regions and supply districts have not been considered in a single model run. "Most efficient operation to date has been achieved at levels of detail... represented by 50-100 discrete geographic demand areas."⁴

Because of the data limitations and the methodology used in the model, the temporal scale of the model is limited. To date estimates have been made through 1985. The Battelle people feel that the model can be extended to make estimates through 1995.

Finally, the model does consider the entire energy cycle from extraction through waste disposal. However, the environmental aspects of the model are limited to sulfur dioxide emissions. The model can be easily coupled with a number of other environmental or residual estimating techniques. When policies affect the prices or cost of energy goods, e.g., strip mine reclamation affecting coal production costs, the model can evaluate the impact of the policy on energy supplies, demands, and prices.

3.1.2 The Economic Aspects of the Model

National energy demands are exogenous inputs to the model. These are systematically proportioned to each of the demand regions. As such the model is not an energy demand model. In particular, the total energy demand is not sensitive to price. Also, fuel substitution is estimated only for power plants. "For the residential, commercial, and industrial fuel users, the only switching permitted in the present version of the model is between fuel grades (sulfur content) but not between fuel types."⁵

The most interesting aspects of the model relate to the supply markets. "The concept of minimum acceptable selling price (MASP) is basic to the operation of the model..."⁶ This price is the cost of production of the fuel plus a minimum acceptable rate of return. In other words, the producer will not sell his product at a price less than the MASP. The purchasing price is determined by the model based on competition within a given demand region. For any supplier, however, this price will always be greater than or equal to the MASP plus the transportation cost. The quantity of any fuel type in any district area for sale at a MASP may be limited. Therefore, the model has the capability of using a stepwise supply function. This method can be used to account for diseconomies of scale or short-run supply constraints on equipment or transportation.

Transportation costs are calculated assuming only one mode of shipping a given fuel from a supply district to a demand region. Therefore, competing transportation modes are not considered in the model.⁷ Since demand is given and substitution of fuels is limited, the Battelle-EPA model does not completely define interregional and interfuel competition. Furthermore, the impact on the final goods market is not explicitly considered in the model. However, the Battelle group feels that competition for petroleum products other than

fuels can be incorporated into the model. This competition is extremely important since refinery operations can be adjusted to produce more or less fuel oil, depending on the relative prices of the nonenergy petroleum products.

3.1.3 Model Capabilities

This section will evaluate the Battelle-EPA model's capabilities relative to the model's ability to predict events, evaluate technology changes, or evaluate policy options.

The Battelle-EPA model can be classified as a predictive model. In particular, it will estimate for any future year (up to 1985) the quantities of each fuel type sold from each supply district to satisfy a given total demand for energy in each demand region. Furthermore, it predicts the selling price. These predictions are made based on the criteria of minimizing national fuel costs. The accuracy of the predictions are, of course, not subject to a prior evaluation.

Technology changes are not explicitly incorporated into the model. However, if such advances affect the production costs of presently used fuels, the impact of the change can be simulated. Because fuel substitution is only possible for power plants in the present version of the model, these forecasted changes will only reflect the power plant responses. In addition, new fuel technology applicable to nonpower plants sectors cannot be readily evaluated.

Because the model was formulated to estimate the effect of sulfur dioxide regulations on the energy market, it should be well suited to evaluate these policies. Although the model is one of the most advanced for such analysis, the lack of detail in the nonpower plant sectors could be a major shortcoming. Other policies that affect fuel prices or production costs can also be analyzed if the demands are not expected to change drastically.

3.1.4 Summary and Conclusions

The Battelle-EPA model is formulated to provide the type of output desired in the regional studies program. Its main disadvantages are the lack of detail in the demand sector, the lack of fuel substitution in the nonpower plant sectors, the omission of the transportation demand sector, and constant

exogenously determined total demands. These shortcomings can be eliminated or reduced or modifying the model.

The model is appealing because it has great spatial detail, which accounts for regional differences in energy prices and consumption. Transportation costs are also an integral part of the model. The details in the supply sector are quite good and reasonably replicate a cost-plus pricing formulation. Competition is considered that allows some producers to receive rents or producer surpluses. Although the supply market used in the model does not explicitly reflect the concepts of a supply function and the elasticity of exploration and development, it does provide a solid basis for estimating supplies and prices. The model is presently being used by the U.S. EPA, where modifications to correct some of its deficiencies are being made.

3.1.5 References

1. Battelle Columbus Laboratories, A Proposal to Develop Energy Price and Availability Projections, p. A-2, April 1973.
2. Chilton, C. H. and R. M. Jimison, "A National Energy Model," Appendix to Battelle Columbus Laboratories, Ibid.
3. Comments from Mr. Freas of the EPA indicated that there would be major data problems in the inclusion of 2-digit SIC level detail.
4. Battelle Columbus Laboratories, op. cit., p. A-2.
5. Ibid., p. A-5. Mr. Freas believes this is a data availability problem, except for the residential market where some conceptual problems may exist.
6. Ibid., p. A-4.
7. New transportation cost estimates are taken from the data contained in the report, Update and Revision of the EPA Energy Quality Model Transportation Cost Matrix for Fossil Fuels Delivered to Electric Utilities, by Foster Associates.

3.2 BAUGHMAN'S DYNAMIC ENERGY SYSTEM MODEL

The Baughman model is designed to simulate the process of interfuel competition. The work was sponsored by the Research Applied to National Needs Program of the National Science Foundation and represents the initial effort of the Energy Analysis and Planning Group at MIT.

The objective of the model is to simulate the combined actions of producers and consumers of energy to obtain market clearing prices and output levels. Baughman calls these interrelated actions the "dynamics of interfuel competition." What the author believes is the essential function of the model is best provided by his own words:

Given the availability of the fuel resources and the levels of demand for each of consuming sectors as a function of time, the model simulates the process in which supply production capacity is constructed and the resources are depleted, the process whereby different fuels are chosen to satisfy demand and resolves these processes into prices and market shares for each form of supply.¹

Figure 3.2 is a flow diagram of the Baughman model that shows its basic interrelationships. The model is driven by exogenously determined demand for energy in each sector. The model disaggregates this total demand into two components: market-sensitive and basic demand. The question answered by the model is: Given the market-sensitive demand for energy in a specific sector, what will the mix of fuels, including electricity, be to meet this demand? The prices of alternative fuels are the parameters used to allocate fuel usage in each sector. These prices are determined in the supply model by generating marginal development curves and short-run marginal cost curves for the primary energy sectors, and average-cost curves for the electricity sector. Using these curves and the estimate of demand for each fuel, the supply price is generated. The supply and demand models are solved iteratively. The price parameter derived in the supply model is used in the demand model to generate new demands. These in turn are used in the supply model to estimate new prices. More details on the supply and demand models are provided in later sections.

Fig. 3.2. Dynamic Energy System Modeling (Baughman)

3.2.1 Model Comprehensiveness

The model estimates the market shares of coal, oil, natural gas, and electricity within the United States. This is done separately for the residential, commercial, transportation, industrial heating, and electricity sectors. The model does not estimate total demand for energy. This variable is provided exogenously and is therefore assumed not to be affected by price. The model can be classified as a supply model in which interfuel competition determines the levels of demand for each competing fuel.

Though not regionalized, conceptually this model could be used on a regional scale, provided transportation and distribution costs are explicitly considered. Presently, the model assumes that these costs are constant multiples of wholesale prices, thus making relative prices at the wellhead or mine mouth equal to the relative prices at end-use locations. Even at the national level of detail, this assumption could greatly affect the appropriateness of using the model results. Furthermore, "the regional dependence of prices makes it questionable whether a national aggregate demand model is meaningful."²

The model considers extraction in the supply model and end use in the demand model. As discussed, the transportation of energy is not included. Energy conversion or processing for electricity, in which the nuclear option is incorporated, is considered, but oil refinery options and new technology, such as coal gasification or liquefaction, are not.

The model structure is flexible enough to overcome some of the above problems. By introducing estimates of new technology costs and by expanding the data base to include transportation/distribution costs, many of the above shortcomings can be overcome.

3.2.2 Economic Aspects of the Model

The present model does not explicitly incorporate interregional or intraregional energy markets. The author,* however, is aware of the importance of doing so, as well as the difficulties involved. One difficulty lies in the definition of parameters and constants used in the model for each specified region. For interregional analysis, the author offered as a possible approach

*"The author(s)" when used in the text of this report represents the author(s) of the respective models.

one used by Debanne, which assumes that "the demand and supply models as given in this work could be completely disconnected, with the transportation problem modeled as a linear program in between."³

The relationship between demand for energy and nonenergy commodities is not explicitly incorporated into the model. A portion of the market-sensitive demand in a sector includes what the author calls incremental demand, which is made up of new consumer needs or growth in that sector. In the industrial sector, for example, the assumption is made that demand for energy will increase by 2.5% per year. The implicit assumption is that value added will increase by approximately this amount with no significant change in the energy coefficient (Btu/\$ value added). Most energy studies assume that the percent change in value added and energy consumption will be equal. In this model, an assumption of decreased growth in industrial output would imply that growth in energy demand will also decrease. If these changes in value added can be related to changes in nonenergy-goods demand, then there is a mechanism for considering induced energy demand.

The incorporation of interfuel competition is the main function of the model, achieved by developing interrelated supply and demand submodels. Each of the models is reviewed briefly in order to describe the economic behavior and mathematical structure assumed.

"There are basically three subsections of the energy supply models. These are the characterization and dynamics of the marginal development cost curves, the logic and dynamics associated with market entry and sustenance of production capacity, and the cost function derived from the development and operation of the production capacity."⁴

The primary fuel supply model is driven by the demand estimates, which are provided by the demand model, and cost of capital, cost per unit of capacity, and reserve level variables that are exogenously determined. In addition, the user must provide any constraints in development, construction time delays, productivity levels, growth, planned surplus capacity, and other parameters that influence the rate of development.

A development function is assumed that results in the marginal development cost curve:

$$MDC = \frac{b(q_0 + r R_0)^2}{r R_0^2},$$

where

- $b \equiv$ cost/unit capacity,
- $r \equiv$ cost of capital,
- $R_0 \equiv$ level of reserves, and
- $q_0 \equiv$ initial capacity.

Under the assumption of purely competitive markets the long-run equilibrium price of the fuel is equal to the marginal development cost. The model allows for short-run fluctuations in price around the equilibrium with the price being higher if there is excess demand or lower if there is excess supply. The short-run cost curve is:⁵

$$SRMC = MDC [Q_D / (Q_C - a)],$$

where

- $Q_D \equiv$ level of fuel demand,
- $Q_C \equiv$ level of production capacity, and
- $a \equiv$ planned surplus capacity.

Finally, to model delays in increasing supply capacity of a given fuel, first-order exponential delays are assumed for allocating resources to a given project and third-order exponential delays are assumed for construction. Figure 3.3 is a simple flow chart that depicts the essence of the primary fuel supply model.

The electricity supply model differs from the primary fuel model in three ways: (1) the nuclear option is considered, (2) prices are based on average costs rather than long-run marginal costs to replicate regulatory pricing policies, and (3) the decision to develop new capacity is a function of system reliability and economics. The desired reliability factor is provided exogenously and is set equal to historical capacity/utilization factors.

The most important behavioral assumptions made in the supply model are: (1) changes in reserves are not a function of price, (2) development

Fig. 3.3. Primary Fuel Supply Method

decisions are primarily determined by price, and (3) the fuel supply sector operates in a competitive market. Structurally, the model assumes exponential reserve depletion curves, exponential delays, a linear short-run supply curve, and transmission/distribution costs that are constant multiples of wholesale prices. An interesting feature of the model is that it does not use comparative statics. The price of a fuel at any given time may deviate from the long-run equilibrium point. Furthermore, the long-run equilibrium price is continually changing as a function of interest rates, reserves, and average unit development costs.

The supply model is used to estimate fuel prices in a given time period. These prices are used in the demand model to estimate changes in fuel demands. It is assumed that the primary determinant of fuel choice is fuel price.

For each fuel type, the model divides demand into two portions. "That portion of demand sensitive to prices over a specified interval of time is termed the market-sensitive demand, and that portion not sensitive to price is called the base demand. The market-sensitive demand is made up of two components -- the replacement demand and the incremental demand."⁶ The incremental demand caused by growth is determined exogenously. The basic demand is also determined exogenously and is not a function of price. This is counter to the theory of capital replacement that would explicitly make the fuel conversion decision a function of energy prices.

The basic equation of the demand model is:

$$Y_i(t+1) = B_i Y_i(t) + d_i(t) \left[\sum_{i=1}^n (1-B_i) Y_i(t) + G(t) \right],$$

where

- $Y_i(t)$ $\equiv$ the quantity of fuel i supplied to consumer sector Y ,
- B_i $\equiv$ the basic demand for fuel i in sector Y ,
- $d_i(t)$ $\equiv$ the fraction of market-sensitive demand that will use fuel i in time t , and
- $G(t)$ $\equiv$ growth in energy demand in time t .

"This equation says that the demand for fuel i in consuming sector Y at time $t+1$ is some fraction B_i of the Y demand for fuel i at time t , plus some fraction $d_i(t)$ of the market-sensitive demand in that consuming sector Y ."⁷

The key variable of the demand model is $d_i(t)$. Since total demand is inelastic, the sum of the d_i 's must equal 1, i.e.:

$$\sum_{i=1}^n d_i(t) = 1.$$

In the Baughman model, the d_i 's are functions of the prices of competing fuels. Because cross elasticities are negative, a log linear functional relationship is required to avoid negative market shares (d_i 's < 0), i.e.:

$$d_i(t) = A_i e^{a_{i1}p_1(t)} e^{a_{i2}p_2(t)} \dots e^{a_{in}p_n(t)}.$$

Using this form, however, there is no guarantee that the d_i 's will sum to one. Therefore, the model normalizes or forces the sum to unity.

Note that the elasticities of the d_i with respect to prices are $a_{ij}p_j$. Thus, the elasticities are functions of price. Unfortunately, some of the behavioral implications that make this elasticity interesting are negated by the normalization of the d_i 's.

"In order to identify both the B's and A's (elasticities) simultaneously, pooled cross-sectional and time series data would be needed."⁸ However, when Baughman originally applied his model, "a set of B's for each consuming sector was present from physical reasoning and a priori knowledge of the life of the consuming equipment in each consuming sector. The A's were set a priori to represent reasonable elasticities for each demand sector."⁹ Furthermore, the parameters were "varied to give a reasonably good fit" to the historical data. Therefore, Baughman's claim that the model was a good predictor, i.e., "the model is working so well," is not justified since this conclusion is based on model results that were adjusted to fit observed data.

The demand model assumes that some consumers are locked into their present fuel consumption pattern. Additionally, the market-sensitive demand is allocated to various fuels based on the prices of competing fuels, and total demand for energy is inelastic. Structurally, the model assumes a log linear demand equation for market-sensitive demand and constant (inelastic) basic demand.

3.2.3 Model Capabilities

The Baughman model is a descriptive analysis of the national energy market in which the behavior of the producing and consuming energy sectors are simulated. Although not explicitly stated, the model can be used as a predictive tool. Because it is a behavioral model, it is attractive for this use. Baughman does caution the reader that for drastic relative price changes "a low level of confidence" should be placed on the demand dynamics of the model. He further states that "this is a restriction of the model's structure, and until one can relate the values of A to the many intangible features involved in the fuel selection process, it will remain a difficulty."¹⁰ This shortcoming seems to be an inherent problem of any model that relies on price elasticities as predictive parameters.

Baughman made a simulation run from 1947 to 1969 and obtained favorable comparisons with actual data. Because the B and A parameters of the demand model were adjusted to conform with observed results, this exercise cannot be considered a demonstration of the model's predictive capabilities.

The model presently does not consider impacts of policy or technology changes, but these could be analyzed if effects on prices were generated. Because demand shifts, which may be caused by technology and policy changes, also affect elasticities, price effects are not sufficient to model the related impacts. Construction delay times, development costs, or basic demand may also be affected. Therefore, the model does not seem as easily adaptable to a planning model as indicated by Baughman.

3.2.4 Summary and Conclusions

The model is an economic model that attempts to simulate the dynamics of interfuel competition. The capability of the model to explicitly simulate supply and demand behavior is its strongest feature. The major weaknesses are: (1) total demand is inelastic, (2) the model is national in scope, and (3) the model is not a planning model.

3.2.5 References

1. Martin Baughman, Dynamic Energy System Modeling - Interfuel Competition, Energy Analysis and Planning Group, MIT (Cambridge, Mass., August 1972).

2. Ibid., p. 76.
3. Ibid., p. 171.
4. Ibid., p. 31.
5. The equation printed in the description of the model is:

$$SRMC = (MDC) (a/1 - Q_D/Q_C) ,$$

which is incorrect, since the price would be infinite if production equals demand, i.e., $Q_D = Q_C$.

6. Op. cit., p. 58.
7. Ibid., pp. 61-62.
8. Ibid., p. 75.
9. Ibid., p. 76.
10. Ibid., p. 65.

3.3 BROOKHAVEN NATIONAL LABORATORY ENERGY MODELS

The Brookhaven National Laboratory Energy Modeling System today consists of two models that were developed for the purposes of technology assessment and policy analysis. These models shall be referred to as the BNL Basic and the Modified Models. The Basic and Modified Models are very closely related and contain many of the same components. The components of the models are:

1. Energy Model Data Base (EMDB)
2. Data Base Creation and Maintenance Program (ERODE)
3. Energy Model Interface Program (EMIP)
4. Energy System Network Simulator (ESNS)
5. Energy System Generator (ESYG)
6. Brookhaven Energy System Optimization Model (BESOM)
7. Reference Energy System (RES)
8. Perturbed Energy System (PES)

The EMDB, a "flexible open-ended, model-independent data system"¹ is the starting point for both systems. ERODE is used to update files in the EMDB or create new ones. ERODE can also serve to facilitate the regionalization of the data base by substituting regional data for much of the nationally averaged

data stored in the EMDB. EMIP is the program that selects the appropriate data from the data base and converts it into a format that is compatible with the remainder of the system. Because the data base was generated for multiple users, i.e., the data base is generalized, EMIP is a necessary component of the system. This is a good feature of the system; however, an auxiliary program such as EMIP needs to be written for each additional use of energy data base. The data base includes efficiencies, emissions, externalities, and costs.

The ESNS model is used to generate energy flows and associated effects (emissions, costs, and resource consumption) for a specified set of energy demand and energy technologies. The ESNS utilizes the reformed data extracted from the EMDB by EMIP. The user is responsible for specifying a link-node network that is required to generate a Reference Energy System (RES) or a Perturbed Energy System (PES). To generate an RES, demand projections and the process allocations (fuel market shares, technology utilization, etc.) are determined by the user. To generate a PES, final demand projections, perturbed process allocations, and process data (costs, pollution, efficiencies are provided exogenously. Figure 3.4 is a schematic of the BNL Energy System Model just described. This is BNL's Basic Model.

Alternatively, the Modified Model generates a Reference Energy System or a Perturbed Energy System using the ESYG and the BESOM submodels. The ESYG model is used to manipulate data and to present it in an appropriate format for the BESOM model. Its function is similar to the EMIP model, which links the data base and the ESNS, though EMIP is still used to retrieve data from EMDB. The BESOM is a linear programming model that "optimally" allocates energy supplies to meet specified energy demands. The many interesting features and potential extensions of this model are discussed in more detail later. At this point, it is sufficient to say that the BESOM model generates a Reference Energy System or Perturbed Energy System. To generate an RES with this model, the method is similar to that used in the Basic Model. To generate a PES, process allocations are not needed as external inputs, as these are optimally determined by minimizing total cost or some other function, subject to a variety of supply and environmental constraints. These constraints, along with a final demand forecast and perturbed process data, are required as external inputs. Figure 3.5 is a representation of BNL's Modified Model.²

Fig. 3.4. BNL's Basic Model

Fig. 3.5. BNL's Modified Model

"The concept of a Reference Energy System is straightforward. It is a description of the major components of the energy system specifying resource consumption, fuel transportation, conversion processes, and end use."³ The authors also describe the RES as a "specialized format for representing the detailed technological structure of the energy system along with resource consumption and emissions to air and water."⁴ The RES is a schematic of the energy flows from extraction to end-use with existing technology. A PES is a changed energy flow network resulting from a technology substitution. Various impacts of the RES and PES are aggregated and compared to determine the marginal effects of the new technology that include environmental effects, costs, and resource utilization.

The Basic Model was developed for strategic planning and assessing new energy technologies. Strategic planning involves the analysis of various energy research and development options in terms of measuring their net social benefit. The goal of the modeling effort was to identify those projects in which the federal government should place its energy research and development funds. Modifications in the model were made for the "analysis of future development of the energy system and of interfuel substitution patterns that may take place in response to constraints on the supply of individual fuels."⁵

Output from the BNL models includes yearly total resource consumption, environmental effects, and costs for the U.S. energy system. Energy systems have been formulated for the years 1977, 1985, 2000, and 2020. Different output occurs if, for example, the RES is obtained from applying the ESNS submodel rather than the BESOM subcomponent. With the former, the user formulates different scenarios on fuel-use patterns, whereas the optimization model endogenously generates energy consumption patterns, given specified constraints and other inputs.

The remainder of this review is devoted to discussing the features of the Basic and Modified BNL Energy System Models. Figure 3.6 shows the structure of the BNL models.

3.3.1 Model Comprehensiveness

In terms of present marketable primary and secondary sources of energy, the RES includes oil, coal, natural gas, and electricity. National estimates are used. More disaggregation of certain fuels is needed; for

Fig. 3.6. Reference Energy System

example, coal should be classified into high and low sulfur in estimating reserves and resources. Work is being done in the estimation of costs and pollution emissions for gasification of coal to high and low Btu gas, production of petroleum crude from shale oil, and coal liquefaction. These are needed to estimate when and to what extent new technology will become competitive within the energy system.

The Basic Model has been applied at the regional level.^{6,7} By combining regional data with a forecasting tool similar to the one used in the national R&D assessment study, an RES for the New York City Region was generated for 1970, 1977, and 1985. The authors of this NYC model see its usefulness as "providing a framework within which the energy system impacts of policy (conservation, allocation, pricing, etc.) and technological options may be evaluated."⁸ A more extensive report of the regional methodology, the "User Guide to Regional Reference Energy Systems," will be prepared in the near future.

Demands for energy are disaggregated into the residential, commercial, industrial, and transportation sectors. Energy use in the residential sector consists of space heating, air conditioning, water heating, and cooking activities. In the commercial sector, the energy demand is assumed to constitute a certain proportion of that consumed in the residential sector. The transportation sector activities include passenger and freight movements by the various modes of transportation. Finally, the industrial sector is disaggregated by industries (cement, aluminum, iron, steel, and petro-chemical) and by functional use (process heat and electric drive). Primary fuel demands for electricity production are determined from the electricity demand estimates derived from the other sectors. The ESNS model "is now designed to handle up to 62 supply and 199 end-use" sectors. This is the Basic Model's level of aggregation. The Modified Model now includes "27 supply categories and 22 demand categories." The sectors analyzed within the Modified Model are shown in Fig. 3.7.

The RES traces the flow of energy from extraction to end-use demand, including in the system intermediate processes, e.g., refining and conversion, transport, transmission, and distribution. This level of detail results in an estimate of total environmental impacts. Before these impacts can provide any useful information, however, they must in turn be estimated on a regional basis.

SUPPLY CATEGORIES	DEMAND CATEGORIES	MISC. ELECTRIC BASE LOAD	MISC. ELECTRIC INTERMED. LOAD	MISC. ELECTRIC PEAK LOAD	ELECTRIC STORAGE				MISC. THERMAL-LOW TEMP.	MISC. THERMAL-INTERMED. TEMP.	MISC. THERMAL-HIGH TEMP.	IRON	PETROCHEMICALS	SPACE HEAT	AIR CONDITIONING	WATER HEAT	AIR TRANSPORT	TRUCK, BUS	RAIL	AUTOMOBILE	SUPPLY SLACK	SUPPLY CONSTRAINT	MARGINAL VALUE
COAL FIRED STEAM ELECTRIC																							
COAL FIRED STEAM ELECTRIC COMBINED CYCLE																							
OIL FIRED STEAM ELECTRIC																							
OIL FIRED STEAM ELECTRIC COMBINED CYCLE																							
OIL FIRED GAS TURBINE																							
GAS FIRED STEAM ELECTRIC																							
TOTAL ENERGY SYSTEMS																							
LIGHT WATER REACTOR																							
LIQUID METAL FAST BREEDER REACTOR																							
HIGH TEMPERATURE GAS- COOLED REACTOR																							
HYDROELECTRIC																							
GEO THERMAL																							
SOLAR DECENTRALIZED ELECTRIC																							
PUMPED STORAGE																							
OIL, DOMESTIC																							
OIL, IMPORTED																							
OIL, SHALE																							
NATURAL GAS																							
SYNTHETIC NATURAL GAS FROM OIL																							
METHANE FROM COAL																							
COAL, UNDERGROUND																							
COAL, STRIPMINED																							
HYDROGEN FROM ELECTROLYSIS																							
METHANOL FROM COAL																							
HYDROGEN-COAL																							
COAL LIQUEFACTION																							
DEMAND CONSTRAINT																							
MARGINAL VALUE																							

Fig. 3.7. Sectors within Modified Model

The authors emphasize the simplicity of the Basic Model for analyzing perturbations (e.g., the introduction of new technology) to the energy system. However, the ability to handle a wider range of policy questions is hindered by the lack of economic and engineering submodels. Also, the exclusion of price as a causal factor of demand, and the exclusion of energy supplier behavior, restricts the usefulness of the model for analyzing policy questions and the impact of new technology. The adaptation of BESOM to the original RES model and the potential for incorporating input/output analysis and supply elasticities into the BNL Energy Modeling System will result in a more useful planning tool.

3.3.2 Economic Aspects of the Model

The Basic Model is a noneconomic accounting model. Market shares of fuels and the cost of energy are determined from expert opinion. Aggregated end-use demand by sector is obtained either by extrapolation or the use of other studies that may not have used consistent assumptions or techniques. Fuel mix projections are not forecasted, but merely represent the user's formulated scenario of how demand will or should be met. The Modified Model, through the BESOM submodel, in part incorporates some economic analysis. The specific economic issues considered or omitted are discussed below.

The Brookhaven models do not include interregional competition for fuel. As national models, the data base consists of national estimates and averages for the parameters incorporated into the models. By regionalizing the data base to include transportation costs of fuels between regions, by obtaining cost curves of energy extracted from the different regions, by projecting regional demand, and by knowing the flow of all energy spatially, the BNL models can be applied on a multiregional level. (As mentioned, the Basic Model has been applied to a single region, though interregional competition is not considered.) Much work would be required to satisfy these requirements. In regionalizing the Modified Model, problems exist in determining the constraints of supply to a particular region. Since the supply available to a region is dependent upon the demands of other regions, the ability of a region to import energy depends on the competitive price bids that each region makes for the energy resource. In addition, since environmental standards vary significantly between small subregions that are geographically adjacent to each

other, regional analysis may be required at a county or multicounty level. Therefore, the regionalization of the BNL models is not as simple a task as developing regional RESs.

The coupling of BESOM with input/output allows the energy sector to interact with the rest of the economy. The purpose of the coupling is to "achieve a better understanding of the complex interrelationships between energy and the other sectors of the industrialized society."⁹ This coupling "overcomes certain difficulties in the conventional I/O approach by providing for technological change and interfuel substitution ...,"¹⁰ i.e., the BESOM model may be useful for incorporating substitution into the I/O technology matrix.

The Basic Model does not consider price and substitution relationships explicitly. The user may choose a scenario based on the effect of variant prices of energy on the decision to use a certain mixture of fuels to meet a specific demand. The Modified Model with its linear programming structure allows for interfuel substitution. But the substitution process differs from the economist's perspective, which assumes that in a dynamic process substitution occurs at the margin with a continuous shifting of demand as relative prices are changing. In the BNL Modified Model, substitution occurs either because of environmental constraints and the scarcity of certain fuels, or because the absolute cost of a given fuel exceeds its social marginal value. The Modified Model assumes that fuel conversion will not be made until the capital stock has reached a given age; i.e., it has been economically depreciated. Therefore, new establishments and those with relatively old equipment are sensitive to market prices. The fuel use patterns of all other establishments are assumed to be the same. Finally, the Modified Model is being expanded to consider substitution for each end-use demand (space heating, process heat, etc.). Since interfuel competition in most studies has been analyzed either by sector or by fuel, Brookhaven's approach is particularly interesting.

3.3.3 Model Capabilities

The BNL models are not designed to predict future energy requirements. In both the Basic and Modified Models, total forecasted demands are exogenously determined and are not sensitive to price. Even though market share analysis is explicit in BESOM, an accurate projection of market shares for each fuel

to meet demand may be distorted because projected end-use demand is exogenously determined. The coupling of the I/O and LP models may eliminate this shortcoming.

Projections of supply availability of energy are obtained from expert opinion of estimates of remaining recoverable resources for each type of fuel. Projections on the costs of fuels were deemed highly speculative by the authors, and therefore were not estimated. Instead, they took studies that estimated costs of new fuels (synthetic crude from shale, synthetic pipeline gas from coal, etc.) and assumed that these costs would set the ceilings on the prices of natural gas and crude oil. This approach postulates that the price paid for fuel derived from new technology will exceed that derived from conventional sources; and, therefore, as marginal producers, the "new technology" suppliers will be the price leaders and the other producers will be earning an economic rent.

The evaluation of technology changes by the BNL models is handled on both the demand and supply sides. A change in the efficiency with which a fuel is used in the specified end-use category causes the total basic energy demand for an end-use category to be altered. On the supply side, the BNL Models explicitly evaluate new technology in terms of costs, emissions, and resource usage. The dynamic linear programming model determines when and to what extent new technology can enter competitively into the energy system, the cost savings that result, and the sensitivity of these savings to assumptions about future supplies and prices of competing resources and technologies. A cost-benefit study of federal R&D expenditures can be done by discounting the savings back to the present and comparing them with the R&D expenditures. Because forecasts of prices, demand, and supply of existing energy forms are needed before the model can project when and to what extent new technology will be an inherent part of a regional energy system, prediction models are essential to the analysis. In general, even though Brookhaven's concept of handling new technology is appropriate, the lack of predictive capability in their models and of a regional data base prevent the use of the model as an efficient planning technique or to provide accurate analysis.

Policy questions are hindered by the poorly specified demand sub-models. The impact of a policy on the prices of fuels are not estimated endogenously. Moreover, their lack of predictive capabilities further reduce their

applicability to evaluate policy questions. Providing analysis to indicate where the government ought to allocate its R&D funds was the initial use of the Basic Model. Extensions of applications to other areas appear to be somewhat limited. Extensions to the Modified Model offer potential for exploring certain regional energy problems.

3.3.4 Summary and Conclusions

The BNL models' strongest feature is their evaluation of technology changes. They also appear to be excellent accounting tools for compiling, storing, and displaying national or single region total costs and impacts for prescribed national energy supply mixes. The models may be adapted to conduct multiregional analysis by inputting region-specific and interregional transportation parameter values. However, regionalization does not simply involve the straightforward process of developing RESs for specific regions. Auxiliary models are required to estimate interregional competition to ensure model consistency. Further work needs to be done to simulate supplier behavior adequately. Finally, the models in their present form have limited use for policy analysis because the reactions to policy changes are based on subjective judgment. Present work being done to couple I/O and LP may lead to a useful technique for estimating substitution effects in the intermediate goods market.

3.3.5 References

1. Associated Universities, Inc., Energy Model Data Base: Users Manual, BNL 19200, p. EMDB-1.
2. We recognize that though some of our comments about the Modified Model may not be entirely applicable to the most recent work done with BESOM (i.e., a "staircase" supply function may be substituted for a supply constraint), the general structure is the same.
3. Associated Universities, Inc., Reference Energy System and Resource Data for Use in the Assessment of Energy Techniques, AET-8, Ap. 1972, p. 3.
4. Kenneth Hoffman, Energy Systems Analysis Program, Brookhaven National Laboratory, BNL 19113-R, p. 2, Jan. 1975.
5. Ibid., p. 2.
6. H. G. M. Johns, et al., Energy Use in the New York City Region, BNL 18880.

7. H. G. M. Johns, et al., Energy Supply and Demand in the New York City Region - An Analytical Framework for Regional Energy Systems Analysis, BNL 19493, Dec. 1974.
8. Ibid., p. 23.
9. Hoffman, op. cit., p. 1.
10. Ibid., p. 2.

3.4 ENERGY MANAGEMENT SIMULATION AND ANALYSIS SYSTEM

The Energy Management Simulation and Analysis System (EMSAS) developed by Decision Science Corporation (DSC) is based upon work carried out for the American Gas Association, the U.S. Department of Housing and Urban Development, and the Executive Office of the President. The EMSAS model has seven major subcomponents: consumption forecasting, energy competition, energy supply forecasting, fuel supply-demand balancing, fuel economics, technology and environmental impact, and energy industry supply submodels. The first four submodels simulate the actions of the energy supply and demand sectors and their responses to changes in energy prices. The function of the next two submodels is to evaluate the impacts of price regulations, environmental controls, and technology advances on the energy market. The last submodel is an industrial decision model, which is not relevant for this review and is not discussed. Figure 3.8 shows the interrelationship between the six submodels of interest.

"EMSAS is designed to analyze energy supply, demand, competing aspects of fuels according to their markets and prices, and environmental/technological impacts."¹ The model uses econometric and trending techniques to estimate energy supplies and demands. Unfortunately, many of the important aspects of the energy markets are assumed away, ignored, or are based on subjective judgments of the user. These problems, as well as some of EMSAS's strengths, are discussed in the following sections.

3.4.1 Model Comprehensiveness

The level of detail of the model varies with the sector being analyzed. Residential and commercial demand is calculated by census region. Only natural gas, electricity, and oil demands are estimated. Coal is assumed to remain noncompetitive in this market regardless of the prices or availability of natural

Source: Decision Science Corp.,
The Energy Management Simulation
and Analysis System, Jenkintown,
Pa., p 2.

Fig. 3.8. ENERGY MANAGEMENT SIMULATION AND ANALYSIS SYSTEM

gas and oil. Furthermore, oil is considered as a substitute fuel for residential and commercial use only in the New England and Middle Atlantic regions. Industrial demand can be estimated in two ways. The first approach calculates total industrial Btu consumption by census region, using a linear regression curve of energy versus personal income in the manufacturing sector. The second approach employs a log-log regression relationship to estimate fuel demand for oil, gas, and electricity for the ten most energy-intensive 2-digit SIC manufacturing industries. This is done on a state-by-state basis. Total demand for electricity is calculated from the residential, commercial, and the industrial estimates made on the census region level. Coal, oil, and natural gas consumption in the power generating sector is then estimated on the basis of power plant characteristics and energy prices.

Each of these sector demand models is discussed in more detail in the next section. The important point to note at this stage of the review is that energy demands are calculated directly on a census-region basis in the residential/commercial, industrial, and electric utility sectors. Industrial demands are also calculated on a state-by-state basis. Transportation and agricultural energy demands are not calculated. Coal is only considered in the electric utility market and oil is only partially considered in the residential/commercial market. Nuclear and hydroelectric market shares in power generation are determined exogenously.

Supply estimates are made for natural gas and oil. Coal is assumed to have no supply constraints, with coal production continuing to expand to meet demands. In recent years, this assumption would have erred significantly because of the shortages in mining equipment and a rapid increase in low sulfur coal demands. The omission of the coal supply sector is a major shortcoming of the model. However, the natural gas supply submodel, although simple, is one of the model's main attributes.

The supply forecasting submodel determines the supply of natural gas and oil on a national basis. "Regional fuel availability is estimated by specifying a number of assumptions regarding transportation and storage."² The details on the regionalization process were not provided, but it seems as though the national estimates are apportioned to eleven supply districts, that correspond to pricing districts defined by the Federal Power Commission. No supply districts are defined for coal.

The EMSAS model is a regional model that is tied to national markets. The common regional aggregations on the demand side are census regions, although industrial demand is estimated on the state level. Supply is apportioned to eleven supply districts. The model has a heavy natural gas bias, but does consider, in part, oil and electricity demand and supply. As suggested earlier, neither coal demand nor supply are adequately treated in the model.

3.4.2 Economic Aspects of the Model

Total residential demands are equal to the product of average energy usage per household for each fuel and the number of households using the fuel, summed over all fuels. Total households is the sum of existing stocks and new construction, which is a function of population and income.

This calculation is made for space heating demand only. In addition, the residential sector is defined as buildings with fewer than five dwelling units. Apartment building demands are included in the commercial sector. Commercial space heating demand is calculated as a percentage of residential demand. Trends are used to estimate total demand from the estimate of space heating demands.

This formulation was justified by DSC because househeating gas saturation in small residences is a major portion of household energy demands. This reflects the natural gas bias of the model. However, this formulation makes the model inadequate for modeling energy demands of oil, electricity, and coal in the residential and commercial sectors. Furthermore, total residential and commercial energy demands are not affected by energy prices because the average consumption of energy per household and total household estimates are not price sensitive.

Total industrial demand for each fuel (except coal) is calculated as a function of fuel prices and other parameters. Therefore, total energy demand in the industrial sector would be adjusted as energy prices change. This means the model implicitly assumes interfuel and energy/nonenergy goods substitutions. However, this energy demand equation is coupled with a market share equation, which explicitly considers interfuel competition. In addition, technology changes are provided for in another submodel. Therefore, the model as applied has an internal inconsistency because total energy demands calculated directly would not agree with total energy demands after explicitly

accounting for interfuel competition and technology changes. Stated differently the model allows for these changes twice, tacitly in some equations and expressly in others, and there is no reason to believe that these two are consistent.

This internal inconsistency can be eliminated by not using the total demand equations when the market share or technology submodels are used. This would require that total demands be provided exogenously, or a new total demand equation must be specified. The model includes the option to use a linear regression curve, which relates total industrial energy consumption with personal income in the manufacturing sector. The calculation is made for each census region, and, in this case, total energy demands would not be a function of energy prices.

Total electricity demands are estimated from the residential, commercial, and industrial subroutines. The portion of this demand satisfied by nuclear and hydro power is provided exogenously or from past trends. The demand for fossil fuels is then calculated based on the operating efficiencies of the power generation stations. The total demand of fossil fuels from power plants is only a function of prices as reflected in the market share analyses conducted in the residential, commercial, and industrial sectors. The model does not seem to consider the relationship of input fuel prices to the price of, and the resultant demand for, electricity.

Summing the energy demands in each sector provides the estimates of total regional energy demands for each fuel. Based on the above discussion, it is clear that the model does not adequately account for energy price changes in estimating total demand.

The interfuel competition aspects of the EMSAS model must also be evaluated separately for each sector. The fuel prices used in all the analyses are the prices paid by electric utilities, which is not a realistic assumption in many regions. Even relative prices of energy would be different for power plants and other sectors. But, this shortcoming could be overcome by obtaining price data for each sector and recalculating the model parameters. The remainder of this section deals with the model structure.

In the residential sector natural gas saturation factors or market shares are estimated for househeating³ in single-family homes (less than five dwelling units per building). Separate estimates are made for new construction and existing housing stocks. For new homes, the dependent variable is

the market share of natural gas, and the independent variable is a "relative Heating Cost Index." This index is the price of electricity divided by the price of gas multiplied by the average number of degree days. It accounts for not only the relative price of electricity and gas but also the total amount of the househeating costs. In the two regions where oil is allowed to be competitive, the price ratio of gas to oil is used as another independent variable. Curiously, DSC theorized that the oil to gas price ratio did not have to be multiplied by degree days, but that the electricity to gas price ratio should be. If total fuel costs are important in the decision to choose electricity or gas, why are they not important in the choice between oil and gas? The form of the equation used, not specified for proprietary reasons, is not common and no justification for the form is given.

Conversions to natural gas from existing housing stocks are estimated by assuming that the conversion rate to natural gas in a given year is equal to the conversion rate in a base year multiplied by the ratio of the market share of gas in new homes in that year to the base year market share.

Total gas consumption for space heating in single family homes, G , is equal to:

$$G = MS_G \times H + E_G + NC_G ,$$

where

- $MS_G \equiv$ the market share of natural gas, as defined,
- $H \equiv$ the energy requirements for space heating in new homes,
- $E_G \equiv$ the gas consumed for space heating by existing gas users, and
- $NC_G \equiv$ the net conversions to gas.

Based on population and income, total residential demand for energy is calculated. Based on past trends, the difference between the gas consumption and total consumption is allocated to oil and electricity. Finally, using trends and proportion techniques, total residential and commercial demands are estimated.

The interfuel competition in this process is restricted to space heating use in new single-family homes. This competition is restricted to gas and electricity in most regions of the country, and oil, gas, and electricity elsewhere. Therefore, the model does not allow coal (oil in some

regions) to penetrate residential and commercial markets regardless of the availability or costs of oil, natural gas, and electricity. Also, the market shares of electricity and oil, after accounting for gas usage, are based on past trends and are not subject to their relative prices. These features of residential/commercial interfuel competition reflect the natural gas bias of the model and make these subcomponents unattractive for a more general application.

The industrial sector market share analysis can be conducted in two ways. As discussed, market shares are estimated directly when total demand is estimated. With this approach, market shares and total consumption are determined by prices considering both the direct and cross elasticities of each fuel, the value added in specific energy intensive industries in each state, the level of urbanization, and the level of income. The model implicitly incorporates interfuel and energy/nonenergy goods substitutions. A more complete model specification might include the cost of capital, land, and labor. Furthermore, the value added in each industry is not sensitive to energy costs, implying that total demand for industrial goods is not affected by energy prices.

Market shares can also be calculated for each fuel using the following equation:

$$\ln MS_i = \alpha_0^i + \sum_{j \neq i} \alpha_j \ln P_j - \alpha_i \ln P_i ,$$

where

- MS_i $\equiv$ market share of fuel i ,
- P_i $\equiv$ price of fuel i ,
- $\ln$ $\equiv$ the natural log function, and
- α $\equiv$ derived constants.

The market shares are then normalized to one to ensure that all of the demand is met.

Using this functional form for estimating market shares, the elasticities of demand and cross-elasticity are equal to the α_i terms. However, normalizing these equations disturbs the statistics such that a theoretical interpretation of the parameters is not possible. This model also implies that the statistical relationship observed, i.e., the elasticities, are constant as demand shifts or as prices change over wide ranges. Because of these

assumptions, econometric equations are more appropriately used for short time periods and small price changes. As such, the EMSAS model may not be adequate for long-range (ten years or more) planning.

Given these market shares, the total demand for each fuel in year t is calculated using the following equation:

$$D_{i,t} = (TD_t - TD_{t-1})MS_{i,t} + (1-AF)D_{i,t-1} + TD_{t-1}(MS_{i,t})AF ,$$

where

- $D_{i,t}$ $\equiv$ demand for fuel i in year t ,
- TD_t $\equiv$ total industrial energy demand in year t ,
- $MS_{i,t}$ $\equiv$ new market share of fuel i in year t , and
- AF $\equiv$ application factor, i.e., that portion of existing demand that is price sensitive.

This formulation assumes that existing demand for a fuel can be divided into price-sensitive and nonprice-sensitive portions. The nonprice-sensitive portion represents inertia in the system and reflects newer equipment that has not been economically depreciated. The key to this formulation is the "application factor," AF , which is provided exogenously by the user. It is usually based on the age of the equipment but could be made a function of fuel prices in a capital replacement submodel. However, this capability is presently not a part of EMSAS.

The EMSAS model can be used in such a way that total demand and/or market shares of fuels are price-sensitive. Supply is also price-sensitive, allowing for potential supply and demand interactions. In the supply model, both exploration and production activity are modeled for natural gas and oil. The key variable in the analysis is the number of wells that will be drilled on a national basis, which are a function of wellhead prices of fuels and other factors. Given the estimate of the number of wells to be drilled, the proportion of the gas and oil well successes, their sizes, and their locations are determined by using simple proportioning procedures that are based on historical observation or ad hoc assumptions. Maximum production levels are based on the vintage of the well (its depletion) and its initial size using a historical curve developed by the Bureau of Natural Gas. Whether this function is also used for oil wells or whether production levels are only calculated for natural gas is not clear.

The supply and demand interface is not well explained in the documentation. The supply/demand balancing submodel seems to apply only to natural gas and it simulates only curtailment options. Because natural gas prices are regulated, this method of equating supply with demand may be appropriate. Curtailment is based on a number of priority ranking options. However, the model does not calculate the reactions, i.e., fuel switching or reduced output, from those who have had their natural gas curtailed. Therefore the model does not allow a fuel user to weigh the costs of alternative fuels with the reliability and cost of natural gas.

Although EMSAS is regional, it does not simulate interregional competition. In particular, transportation or distribution costs from a supply region to a demand region do not affect the flow of energy between regions. Interregional shipments of fuels are exogenously provided by the user in the form of an origin-destination matrix. The elements of the matrix are the fractions of a supply district's output that will be shipped to a given demand region. If excess supply in a particular demand region results from this allocation, it is apportioned to the areas with excess demand. Energy flows may also be determined through simple proportioning such as allowing for each supply district to ship to each demand region in proportion to its fraction of total demand. None of the allocation procedures simulate economic decisions made by producers or users of energy. As in other subcomponents of the model, the allocation procedures are described only in terms of natural gas, creating the impression that energy flows are only estimated for natural gas.

Although the model does react to price changes, the simulated actions are either incorrectly or incompletely defined. As such, the model needs to be modified and expanded before it is suitable for analyzing energy supply and demand interaction. However, some of the subcomponents of the model are interesting and valuable, and the structure of the model makes it relatively easy to make refinements.

3.4.3 Model Capabilities

The EMSAS model has two subcomponents that are designed to conduct policy analyses. The Fuel Economic submodel evaluates the effect of price-setting regulations, and the Technology and Environmental Impact submodel estimates the effects of pollution controls and new technology on the energy

system. Both of these models simulate the impacts by altering energy prices. Since the methods used to analyze price setting and technology changes are not documented, an evaluation of these features of the model cannot be provided.

Environmental regulations in the EMSAS model are narrowly defined as sulfur dioxide controls. These controls may vary by region and affect the energy system in two ways. First, supply limits of low sulfur fuels in each supply region are estimated, using current ratios of high- and low-sulfur production levels of coal and oil. These limits constrain the availability of the fuel independently of price. As such they are not entirely realistic. Second, when low sulfur fuels are not available, the model increases the price of a fuel to account for fuel desulfurization or stack gas desulfurization. The choice between fuel desulfurization or stack gas desulfurization is made by comparing the costs of these options, but low-sulfur fuels are always assumed to be the least-expensive option. Another problem with the model is that sulfur regulations may not be constant throughout a census region. Since the level of analysis in the model is restricted to census regions, the results may err significantly.

3.4.4. Summary and Conclusions

The EMSAS model has a number of positive features. To begin with, it is simple and relatively inexpensive to operate. The structure of the model is suited for comprehensive analyses, including special models for simulating policy decisions and technology changes.

On the other hand, the model has some serious shortcomings. First, it is comprehensive for natural gas only. Many of the features of the model are not designed for other fuels, which has sometimes resulted in a model specification that is not easily adaptable. Yet, the details within the natural gas sector may make the model suitable for analyzing the market potential of gasified coal.

The model also has some internal inconsistencies that may be avoided if operated properly. These occur when total demand in the industrial sector is estimated using the price-sensitive equation and then the market-share analysis is employed. The inconsistency arises because the model generates two fuel-use patterns with the same set of prices. There is no reason to believe that these two market-share estimates will be consistent. In addition,

the authors of the model state that it implicitly assumes a constant relationship between the interregional and intraregional fuel prices. If this is correct, then any pricing policy that alters this relationship cannot be modeled.

3.4.5 References

1. Decision Sciences Corporation, The Energy Management Simulation and Analysis System, Jenkintown, Pennsylvania, p. 1.
2. Ibid., p. 1.
3. It is difficult to tell from the description of the model, but it seems as if househeating does not include air conditioning.

3.5 HUDSON-JORGENSON ENERGY MODEL

The energy model constructed by Hudson and Jorgenson¹ is an attempt to combine input/output analysis and econometric forecasting into an integrated approach for energy analysis. An econometric model is used to forecast long-run demand for sectors in the economy. Supply conditions are predicted using a unique input/output model that incorporates the effects of price changes on production processes, and consequently on the input/output coefficients. The two sides of the market are combined to solve for the prices and quantities of goods and services that will clear the market at future dates.

The model is designed to relate energy supply and demand to the growth of the country. It treats energy use as one interrelated part of the entire economy and takes into account energy used both as a final and as an intermediate product. To focus attention on and to provide detailed data about energy, the economy is disaggregated for this model in such a way that five of the nine sectors used are energy sectors. The model is designed to estimate long-term (the authors use 25 years in their example) forecasts of the use of and prices for energy in the economy, as well as predictions for the typical macro-model aggregates (e.g., GNP). The model can give alternative forecasts for different policies that affect fuel prices directly (e.g., different tax schemes).

The output from the H J model is the result of complex interactions between an interindustry transaction and a macro-growth model. Each of these models has a number of subcomponents as shown in Fig. 3.9. The macro-growth model, with its submodels for business and household behavior, provides data that flow into the interindustry model. The interindustry model, making use

Fig. 3.9. Hudson-Jorgenson Model

of producer behavior submodels for each of the nine sectors considered, determines the coefficients for the input/output model, as well as the product prices. Final demands of personal consumption expenditures are derived from the consumer behavior submodel. This information is combined with the aggregate totals generated in the growth model and various exogenous inputs to generate estimates of prices and quantities of products produced, as well as the allocation of the use of all products, including energy, to the appropriate sectors.

3.5.1 Model Comprehensiveness

The model provides detailed supply, demand, and price information for nine sectors. Information is determined both for final products and for energy and other goods and services as intermediate product inputs. There are four nonenergy sectors (1-4) and five energy sectors (5-9) used in the model:

1. agriculture, nonfuel mining, and construction
2. manufacturing, excluding petroleum refining
3. transportation
4. communications, trade, services
5. coal mining
6. crude petroleum and natural gas
7. petroleum refining
8. electric utilities
9. gas utilities.

The model estimates supply and demand interactions for coal, oil, natural gas, and electricity. The demand for energy by the manufacturing, agriculture, transportation, and communication industries are estimated as intermediate demands in the I/O formulation, and the demands from businesses, households, government, and exports are considered in the final demand vector. (Only business and household demands are estimated endogenously.) Although all appropriate sectors are considered in the model, the level of detail within each sector is not sufficient for many kinds of analyses.

The model is national in character and is concerned with aggregate national usage of energy. Within this context, the model is flexible in the sense that additional sectors could be included in the analysis if the necessary data were available. In particular, more manufacturing detail would be desirable. However, the extent to which it can be expanded in practice is limited because

of the model's complexity. The problems of increasing the detail of the model would become even more pronounced if the model were to be made multiregional.

3.5.2 Economic Aspects of the Model

Because all of the components of the model are national in nature, the model does not consider interregional competition. The mechanisms by which interfuel competition and total energy demand are incorporated in the model are quite complex because they are a combination of the I/O and econometric analyses. In the following, a brief description of the components of the model is presented and the economic assumptions made are identified.

The input/output model is unusual in that the input/output coefficients are determined endogenously. A submodel consisting of nine producer behavior models, for the nine sectors, uses the relative prices of capital and labor (from the macro-growth model) along with prices of imports to solve simultaneously for the prices of all inputs and products, as well as for input/output coefficients. The producer behavior models allow for substitutions among inputs in the production process, as a response to changing relative prices, and the prices of the inputs determine the prices of the final products. The quantities of each product used as inputs must be equal to the quantities supplied, both at the price for the input, and given the relative price structure for all inputs. These coefficients can then be combined with the aggregate information from the macro-growth model to give detailed information for each of the nine sectors. This process is diagrammed in Fig. 3.10.

The model of producer behavior generates the interindustry demand for products for the nine intermediate-goods sectors. The primary objective of the model is to account for the interrelationships between the relative demand for energy and the demand for capital services, labor services, and nonenergy inputs. Also, the equations explore the interrelationships among relative shares for the five types of energy included in the model: coal, crude petroleum and natural gas, refined petroleum products, electricity, and natural gas as a product of the gas utility.

Initially, the three primary factors of capital, labor, and imports, as well as the nine intermediate sectors, are aggregated into capital, labor, energy, and material sectors. The producer behavior model is applied to these aggregates. A "translog price possibility frontier"² function is used to

Fig. 3.10. Interindustry Econometric Model

SOURCE: Hudson, E. A. and D. N. Jorgenson, U.S. Energy Policy and Economic Growth, 1975-2000, The Bell Journal of Economics and Management Science, Autumn, 1974, p. 474.

estimate the prices of each of these aggregate sectors. These are functions that are quadratic in the logarithms of the prices of the inputs; for example:

$$\begin{aligned} \ln AI + \ln PI = & \alpha_o^I + \alpha_K^I \ln PK + \alpha_L^I \ln PL + \alpha_E^I \ln PE \\ & + \alpha_M^I \ln PM + 1/2 [\beta_{KK}^I (\ln PK)^2 + \beta_{KL}^I \ln PKPL + \dots] , \end{aligned}$$

where

- AI $\equiv$ an index of the level of Hicks-neutral technology in industry I,
- PI $\equiv$ the price of good I, I = K,L,E,M; and
- α, β $\equiv$ are derived coefficients.

Since the relative share of the jth intermediate input is:

$$\frac{\partial \ln PI}{\partial \ln PJ} = \frac{PJ \times X_{JI}}{PI \times X_I} = \frac{PJ}{PI} \times A_{JI}$$

where

- X_{JI} $\equiv$ the quantity of good J used to produce I,
- X_I $\equiv$ the quantity of good I produced, and
- A_{JI} $\equiv$ the input/output coefficient; i.e., the quantity of good J used to produce a unit of good I;

the input/output coefficient for each of the four aggregated sectors can be calculated using the following equations:

$$\begin{aligned} A_{JI} = \frac{J_I}{X_I} = & (\alpha_J^I + \beta_{JK}^I \ln PK + \beta_{JL}^I \ln PL \\ & + \beta_{JE}^I \ln PE + \beta_{JM}^I \ln PM) / (PJ/PI), \quad \forall I, J = K, L, E, M. \end{aligned}$$

These equations are used to account for the competition between energy and other goods in the production process and the relative shares of each of these goods is a function of their prices.

Given the results of this initial analysis, the model then considers interfuel competition by determining relative shares of each of the energy sectors that make up the energy aggregate. (The model also disaggregates

the materials sector.) A translog price possibilities frontier is again used, so interfuel competition is also determined using fuel prices.

The energy input/output coefficients obtained in the initial step, b_{ej} , are defined as the quantity of energy required per unit output of j . The energy I/O coefficient obtained in the second stage, c_{fe} , are defined as the quantity of fuel f required per unit of energy. Therefore, the I/O coefficient that is used in the energy I/O model is:

$$a_{fj} = c_{fe} \cdot b_{ej}.$$

Similarly, the I/O coefficients in the other sector are obtained.

As can be determined from the above discussion, the producer behavior model allows for substitution of nonenergy and energy goods, and substitution within the energy sector based on the prices of the competing commodities. These substitutions are made for intermediate-goods demands only.

The producer behavior model assumes separability of inputs in each aggregate, Hicks-neutral technology change, constant returns to scale, and perfect competition. The separability of inputs implies that the market share of each fuel is only dependent on fuel prices. The Hicks neutral technology change assumes that, *ceteris paribus*, technology changes over time will not alter the relative shares of inputs in a production process. This principle implies that technology change will not alter the relative demand for energy in any of the sectors. This assumption would, of course, be violated for any energy conservation technology change. Thus, the use of the H-J model for conservation policies may be restricted to the final demand (household and business) sectors.

The final demand vector used in the I/O model is made up of four components: (1) personal consumption expenditures, (2) gross domestic private investment, (3) government purchases and services, and (4) exports. The latter two are provided exogenously. Aggregate investments are estimates in the macro-growth model. Investments are allocated to each of the nine sectors in the I/O model using exogenously-determined factors. The macro-model also generates an estimate of total personal expenditures, which must be allocated to each of the nine I/O sectors (crude petroleum and natural gas are not sold

directly to consumers), housing, consumer durables, and noncompetitive import sectors are determined using the price of each of these commodities and total expenditures as explanatory variables. Therefore, for the personal consumption expenditure portion of the final demand vector the relative shares of each fuel and total energy (i.e., their sum) is a function of their prices and the independent variables of the macro-model that affect personal consumption and investment.

The macro-growth model consists of business and household sectors plus exogenous government and foreign sectors. The model is dynamic due to the link between investment and the change in capital stock, as well as the link between the prices of capital services, and the change in the price of investment goods. The macro-model generates GNP and its component parts in real terms, as is typical for such a model, but it also generates the relative prices for capital and labor, which are needed for the interindustry input/output model. The macro-model is diagrammed in detail in Fig. 3.11. The price of energy is not included as an explanatory variable in the growth model. Therefore, the cost of energy does not affect economic growth in the H-J model.

The approach in general includes supply factors that are often absent from short-run models but are necessary for long-run forecasting. The model contains the constraints that the quantity supplied equals the quantity demanded for each of the energy types (and other products), and also that the quantities supplied and demanded are consistent with the price structure for the different types of energy. This price structure is determined in the interindustry model, which takes into account the energy used in the energy and nonenergy sectors. The model allows price to adjust to clear each market: While the supply conditions are not clearly explained, this is a clear advantage over simply assuming that demand will be met in some unspecified manner.

Total demand for energy goods and nonenergy goods are calculated using traditional I/O procedures. That is, output is equal to:

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

where

$X \equiv$ output vector,

$I \equiv$ identity matrix,

Fig. 3.11. Macro-Econometric Growth Model

SOURCE: Hudson, E. A. and D. N. Jorgenson,
The U.S. Energy Policy and Economic Growth, 1975-2000,
 The Bell Journal of Economics and Management Science,
 Autumn 1974, p. 489.

$A \equiv$ input/output technology matrix, and
 $Y \equiv$ final demand vector.

Similarly, prices are equal to:

$$P = V(I-A)^{-1},$$

where

$P \equiv$ the price vector and
 $V \equiv$ the value added vector.

In this model, value added is comprised of capital, labor, and imports. The quantity of these inputs can also be estimated given the I/O coefficient and the output vector X .

In summary, the H-J model, through the interaction of the interindustry and macro-growth models, estimates fuel market shares (i.e., interfuel competition) as well as the total demand for energy, as a function of fuel prices. The latter effect is caused by a substitution between energy and nonenergy goods, not because growth may be affected by energy prices.

The model is not regional in nature, though there is some potential for regionalization. If data were available, an input/output model could be developed for a region. Imports and exports would be from or to other regions rather than from or to other countries. The producer behavior models could be either regional if there were something to be gained, or national if the industries in the region were typical of or could be related to the nation as a whole. The macro-model would pose more difficulties. Generally, these models are difficult to design for a region. The Wharton School of Business at the University of Pennsylvania, however, is apparently working on this problem and has some functioning regional models. Again, it will be possible to get the necessary predictions from a national macro-model if the region is typical of the nation, or if stable relationships between the region and the nation can be identified. Making the model multiregional poses significant practical problems, but is conceptually possible.

Because of the valuable nature of the output provided and the completeness of the approach, regionalization efforts for this model may be worth

pursuing. Data problems may prove to be the most difficult barriers to regionalizing the model successfully. Note, however, that the high degree of aggregation necessary because of the complexity of the model may mean that the sectors are so broad that little interregional difference would emerge. Also, any regional study group would have to question whether the high cost to set up the model and its complexity justified the output; this would, of course, depend on the size of the region and the questions being asked.

3.5.3 Model Capabilities

The H-J model is designed to combine supply and demand projections to give a forecast of energy use and prices by sector for each year into the future. As a starting point, the authors present forecasts of energy use at five-year intervals from 1975 to 2000; they compare their forecasts with those of other models and find that they are in the same range. Their estimates of energy use are, however, slightly lower than many of the others, probably resulting from the fact that this model allows input substitutions in response to relative price changes; in this case, substitution away from energy in response to its relatively higher price.

The thrust of the energy forecasts is in the forecasts of the macro-economic variables that are taken from a very sophisticated and widely-accepted macro-growth model developed by Data Resources, Inc. This model, which explicitly incorporates supply constraint impacts on U.S. economic growth, is capable of making long-run projections. The projections of the coefficients, however, are dependent upon elasticities that may not hold in the future. The time series data used to develop the elasticities were taken from a period of time (1947-1971) in which there were generally decreasing relative energy prices. These elasticities may not be appropriate for the future when relative energy prices are expected to increase. This potential shortcoming of the model is common to most econometric models because they imply that historical relationships will continue into the future. With an expanded data base covering a number of years with relatively increasing energy prices, the appropriateness of these elasticities can be tested.

The authors claim that "our approach can be used to project U.S. economic growth and energy utilization for any proposed U.S. energy policy."⁴ Based on our definition of energy policy, this statement is incorrect. The policies

that the model can evaluate endogenously are those that directly affect prices, such as a taxing policy. (Since energy imports are provided exogenously into the model, it can estimate the impact of changing import quotas -- provided it is assumed that imports equal the quotas set.) Conservation, environmental, and other policies that affect the price of energy indirectly can be modeled only if an auxiliary program is generated to simulate the impact of these policies on input prices.

The model could handle some technology changes through the I/O model if auxiliary programs were developed for determining the market potential of the new technologies. For example, coal gasification cannot be modeled without adding a coal gasification sector to the I/O table. This provision would require estimates of the appropriate I/O coefficients for coal gasification and an estimate of the econometric coefficients to determine the market share of this new method of processing energy. Both of these analyses would require major efforts. Another feature of the model that limits the types of technology changes it can evaluate is the assumption of Hicks neutral technology. As mentioned, this assumption would be violated if a technology change altered the relative shares of each input in the production process. Since many technology changes will be designed to conserve energy and may come about through regulation or public concern, rather than through relative price changes, the Hicks neutral assumption would not apply and the model could not evaluate these changes. If a sufficient number of these technology changes occur in the future, then the projection made by the H-J model may err significantly.

The H-J model, therefore, has a suitable structure for analyzing energy policies that affect energy prices. But, only those policies that directly affect price can be evaluated without first constructing additional models to simulate the price effects of the policy. Technology changes are not easily incorporated into the model, and in some cases, may violate the assumption used. On the other hand, the model is capable of making forecasts of energy consumption and prices -- provided that the parameters of the model are appropriate for the future and there are no technology changes that would violate the Hicks neutral assumptions.

3.5.4 Summary and Conclusions

The H-J model treats energy as one part of an interacting economic system. Supply and demand conditions affect energy use, both as an intermediate and as a final product, through the economy. These supply and demand conditions are considered explicitly and in some detail. The effect of absolute and relative prices for energy is incorporated into the model. Through substitutions among inputs and among final products in response to price changes, the level and pattern of energy use is affected. In contrast to the conventional energy balance approach, the model incorporates the energy sector as only one portion of the total economic system. It is a general equilibrium model in the sense that all markets (energy and nonenergy) are cleared simultaneously, given prices of all inputs and outputs in the economy. In this sense, too, the model is very useful in undertaking a comprehensive economic impact analysis concerning the effect of the energy sector on such variables as employment, income, consumption, and the general price level. Also, the impact of these macro-variables on energy parameters can be simulated.

A major strength of the model is its theoretical approach. Supply and demand aspects of the energy question are considered separately and then are combined to determine the final effect. Simple macro-models deal only with demand, while traditional input/output models describe the supply side of the market and assume fixed input proportions. This approach integrates supply and demand and relates this to energy use, growth, inflation, prices, etc.

While this model is realistic, it is -- not surprisingly -- very complex. But its complexity may limit the model's usefulness for certain questions and regional applications. Another weakness of the model is that it does not consider in detail the behavior of energy producers; for example, the problems of estimating the supplies of oil and natural gas because of exploration difficulties, price regulating, depletion allowances, etc., are not addressed.

Many exogenous inputs are made into the model, items such as export prices and the allocation of investment and government spending by sector. While these assumptions are clearly identified by the authors, specifics for them are not often supplied. To complete an evaluation of the model, this additional information is necessary. The model could be used with different

exogenous inputs, but the users must be able to judge the reasonableness of the assumptions. Conducting sensitivity analyses for the important assumptions would be useful to determine to what extent the energy information provided by the model depends on and is sensitive to the various exogenous parameters used.

At several points in their presentation the authors mention factors such as energy conservation, basic changes in the economy, new sources of energy, changes in the use of automobiles, etc. The extent to which these factors are outputs from the model and to which they are assumptions is not clear from these discussions.

This model offers a theoretically appealing analytical framework to evaluate energy use in the economy on a national level. The potential for regionalization and additional sectoral detail should be examined to determine whether such modifications would be worth further effort.

3.5.5 References

1. Hudson, Edward A. and Jorgenson, Dale W., U.S. Energy Policy and Economic Growth, 1975-2000, The Bell Journal of Economics and Management Science, pp 461-514, Autumn 1974.
2. Ibid., p. 476.
3. For more information on indirect utility functions, see Christensen, L.R., Jorgenson, D. W., and Lau, L. J., Transcendental Logarithmic Utility Functions, The American Economic Review, June 1975.
4. Hudson and Jorgenson, op. cit., p. 462.

3.6 KALTER'S PARAMETRIC MODELS OF FOSSIL FUEL MARKETS

The report described parametric models of the fossil fuel (coal, oil, and gas) markets at two levels. First, models for individual fuels are based on historical data and assumed interactions of supply, demand, and price. Supply and demand elasticities and other significant variables are parametric, which can be specified by the user. Secondly, the individual fuel models are linked through a constraint on price differential. The model is exercised for likely values of the parameters, and the implications of alternative parametric values and alternative government policies are discussed.¹

These models were developed by Robert J. Kalter for the Assistant Secretary for Program Development and Budget in the U.S. Department of the Interior. The purpose of the models is to provide a comprehensive analysis of energy markets that could be used to evaluate the impacts of various government policies. The models are described as parametric; in the author's words, "A parametric model does not try to empirically estimate relationships between dependent and various explanatory variables. Rather such a model begins with the assumption that a theoretical relationship exists and has a particular form."² The parameters can be set by the user on the basis of judgment or from empirical studies. Models of this type are useful for identifying those parameters that most significantly affect modeling conclusions. If the decision suggested by the model does not change for a wide range of parametric options, e.g., relative impacts of a policy do not change, then the model can also be useful for ranking alternative policy options. This ranking is possible even if the absolute impacts of the policies cannot be readily determined.

As indicated above, two models are described, the first assuming independence between fuels, while the latter tries to account for interfuel competition. "Both approaches focus on national supply and demand for the fuels considered and are primarily concerned with wellhead or mine-mouth prices."³ Burner-tip prices are used for the fuel interdependence approach.

3.6.1 Model Comprehensiveness

The model explicitly considers coal, oil, and natural gas, but the conceptual framework of the model can be extended to include all primary sources of energy, e.g., uranium. A major drawback of the model is that all demand sectors and regions are aggregated into a single demand. Similarly, supply is defined as a single aggregated variable. As such, the equilibrium price generated is an average price to all sectors in all regions. The author is aware of this feature and cautions the reader to use appropriately defined parameters when applying the model. He states, "It should be noted that the elasticity values are assumed to be composites or weighted averages of specific market segments and regional differences."⁴

Another shortcoming of the model is that transportation costs are not accounted for. Supposedly these costs are included in the "burner-tip" price used for the interfuel competition model; but the use of this aggregative

price may incorrectly define the substitutions seen in the model, since a differential of average price is not the same as an average of weighted difference prices. The one reason for this variance is that the weights used to obtain the average price change as demand and supply shift. It is difficult to determine at this time what errors are introduced by the simplified assumptions used in the models.

The Kalter model does not seem to be readily adaptable to regional analysis, since an appropriate supply analysis would have to include inter-regional competition -- which is dependent on relative fuel prices between regions rather than the selling price within a given region. Yet, the concepts of supply and demand elasticity may be useful for some aspects of a regional analysis. The way in which Kalter incorporates long-term and short-term elasticity, demand and supply shifts, and substitutions may be reasonable as first approximations. Certainly the simplicity of the model and its relatively small data requirements are advantages.

3.6.2 Economic Aspects of the Model

The model is based on microeconomic theory. However, because of the aggregate nature of the model, intraregional, interregional, and final goods markets are not considered. As discussed above, there may be some difficulty in applying this approach on a regional basis.

On the other hand, the model does consider price relationship and substitutions resulting from price differences. Another interesting feature of the interfuel model is that supply and demand are determined simultaneously, therefore, determining the total quantity of energy solid.

The basic principles of model development for a specific fuel can be summarized in the following manner:

$$D_t = D_0 + \left(\sum_{t=1}^t D_{t-1} \cdot \lambda_t \right) \text{ at } P_0, \quad (1)$$

$$Y_t = D_t - (S_0 + M_t), \quad (2)$$

and
$$X = Y_t / ((D_0 \cdot \alpha \cdot \gamma_t) + (S_0 \cdot \beta \cdot \theta_t)), \quad (3)$$

where

- $P_0 \equiv$ fossil fuel price in base year,
- $D_0 \equiv$ fossil fuel demand in base year at P_0 ,
- $S_0 \equiv$ fossil fuel reserve discoveries, extensions, and revision in base year at P_0 ,
- $\alpha \equiv$ long-run demand elasticity for fossil fuel,
- $\beta \equiv$ long-run supply elasticity for fossil fuel,
- $\gamma_t \equiv$ percent of long-run demand elasticity in effect in time period t ,
- $\theta_t \equiv$ percent of long run supply elasticity in effect in time period t ,
- $Y_t \equiv$ gap between demand and reserve finds in time period t at price P_0 ,
- $\lambda_t \equiv$ percentage shift in demand at price P_0 in time period t ,
- $M_t \equiv$ imports in time period t ,
- $X \equiv$ percentage change in price from P_0 to market clear (or reduce Y_t to zero) and given $\alpha, \beta, \gamma_t, \theta_t$.

Equation 1 estimates demand shifts due to nonprice influences. Equation 2 states that the excess supply or demand is equal to demand less additions to reserves less net imports. "The heart of the model is Equation 3. It is derived from the standard price elasticity formula. Both long-run supply and demand elasticities and their associated lags are considered."⁶ Given the calculated percent change in price, the elasticities of supply and demand, and the percent of the elasticities in effect, i.e., lags, the changes in demand, supply, and price are calculated as follows:

$$\Delta D_t = X \cdot \alpha \cdot \gamma_t \cdot D_0 ,$$

$$D_t = \Delta D_t + D_0 ,$$

$$\Delta S_t = X \cdot \beta \cdot \theta_t \cdot S_0 ,$$

$$S_t = \Delta S_t + S_0 ,$$

and

$$P_t = P_0 + (P_0 \cdot X) .$$

In the interfuel competition model, the user defines a cost-per-Btu differential that cannot be exceeded. If the above model indicates that the cost (burn-tip price/Btu) differential between two forms of energy is above the maximum differential, then the annual demand shifts are modified to bring the cost differences below this level.

A major shortcoming of this approach is that the interfuel competition depends solely on the exogenously-determined maximum price differential percentages. Since there is no a priori knowledge of the magnitude of this parameter, the results may not be valid.

3.6.3 Model Capabilities

If the parameters used in the model are mostly subjective, then it would be unrealistic to view the model results as predictions of future events. But, if empirically derived parameters are used, the model could be used to estimate future national fuel demands and supplies. Weighted average prices of fossil fuels are also determined by the model.

The author claims that the model can be used to evaluate the impacts of various policies from deregulation of natural gas to environmental control. The claim is valid, provided reasonable estimates of the effects of these policies on prices can be determined. Similarly, technological changes can also be modeled to ascertain their impacts on energy consumption if the price impacts can be determined.

The ability to estimate the price effects on the aggregated scale required, due to policy or technology changes, is the critical issue relative to the appropriateness of the model for such analyses.

3.6.4 Summary and Conclusions

The Kalter model's main advantage is its simple structure and the simultaneous consideration of supply and demand. If the relative impacts of policies or technology change do not vary greatly with a wide range of parametric options, then the model can be quite useful for ranking alternative policies or energy R&D programs. This is possible even if the absolute estimates of energy supplies, demands, and prices are incorrect. However, auxiliary models are required to determine the impact on the price of fuels of the policy options or technology changes.

The model's basic weakness is its lack of detail. The only disaggregation is related to fuel type, which might lead to erroneous conclusions or limit the model's usefulness. For example, the costs of fuel substitution, the age of the capital stock, and the regional price differentials of fuels are not taken into account in the estimated fuel substitution. The model user would have to rely on the average estimated price differential and the minimum required price differential parameters to adequately account for the substitution decision process.

3.6.5 References

1. Kalter, Robert J., "Economic Analysis of Fossil Fuel Markets Using Parametric Models," abstract, to the Department of the Interior, Dec. 1973.
2. Ibid., p. 4.
3. Ibid., p. 3.
4. Ibid., p. 21.
5. Ibid., p. 21.
6. Ibid., p. 8.

3.7 PROJECT INDEPENDENCE EVALUATION SYSTEM

"Project Independence" was created in response to the Arab oil embargo of 1973 and to "the realization of the potential costs of being increasingly dependent on foreign sources of energy."¹ The original goal of Project Independence, established by the President, was to provide a blueprint for "energy independence for the United States by 1980."² However,

there was considerable divergence of opinion ... regarding the meaning of energy independence To some, energy independence is a situation in which the United States receives no imports; i.e., it produces all of its energy domestically. To others, independence is a situation in which the United States does import to meet some of its energy requirements, but only up to a point of 'acceptable' political and economic vulnerability.³

Nevertheless, despite its political origin, Project Independence set out to create a model of the nation's energy system that would provide an objective tool for measuring and evaluating various policies regarding energy strategies.

The model was to be as comprehensive and inclusive as possible, and was designed to investigate such broad strategic options as increasing domestic energy supply, conserving and managing energy demand, and/or establishing standby emergency programs. The model was designed to evaluate any given policy in terms of its impact on:

- (a) development of alternative energy sources,
- (b) vulnerability to import disruptions,
- (c) economic growth, inflation, and unemployment,
- (d) environmental effects, and
- (e) regional and social effects.

Although the Project Independence Report disavows any intent of being "a 'blueprint' for reaching zero imports by 1980"⁴ or of making any specific policy recommendations, a large proportion of the Report is devoted to a detailed analysis of eight scenarios for the energy situation in the United States in 1985, using four policy options: "Business as Usual," in which no government action towards altering current trends in energy production or usage is taken; and the three "broad strategic options" mentioned above. Each of these four cases is evaluated based on two different world prices of crude oil, \$7 and \$11 per barrel. The evaluation for each of these scenarios is based upon a detailed analysis of the output provided by the Project Independence Evaluation System (PIES) model.

The above scenarios are not intended to recommend any specific energy policy, but are presented to illustrate the model's capabilities and to indicate how the model can be used to provide "the analytical and factual basis for focusing debate on the difficult choices and tradeoffs, and selecting a national energy policy."⁵ Nevertheless, the large amount of space devoted in the Report to a discussion of these scenarios, compared to the relatively small amount of space allocated to a description of the model itself, makes it difficult to keep these disclaimers in mind and to separate the model itself from some of the specific outputs it has produced. This difficulty is compounded by the fact that the model and submodel descriptions are interspersed throughout the report with the scenario evaluations.

The Project Independence model itself

was shaped by three underlying considerations: the importance of making explicit the dependence of supply, demand, and policy alternatives on price; the need to consider domestic supply, demand and constraints on a regional rather than a national basis, and the desirability of structuring the overall energy system in one cohesive, analytical framework.⁶

The organizational structure of Project Independence is shown in Fig. 3.12. In order to obtain detailed supply and demand estimates by region, several hundred government and private experts were organized into task forces. A brief description of each task force and its responsibilities follows.⁷

Resource Development. This task force was composed of separate subgroups, concentrating on coal, oil, gas, nuclear energy, synthetic fuels, shale oil, solar energy, geothermal energy, and facilities, respectively. Each was headed by the particular federal agency with expertise in the respective area. Each group had the responsibility of developing regional price-sensitive energy supply curves. The regional breakdown used by each group, though, was different and was based upon the traditional regions used by each energy or fuel type (e.g., coal was divided into the 7 regions as established by the Bureau of Mines, oil into 12 regions -- including offshore areas -- as established by the National Petroleum Council). "In addition, manpower, equipment, materials, and construction inputs needed to support the various levels of production."⁸

Energy Demand and Conservation. "The assignment of this group was to develop price-sensitive demand forecasts for major fuels and economic sectors, by region of the country, and to estimate and incorporate the effects of nonprice-induced energy conservation initiatives into the demand forecast."⁹

Quantitative Analysis. This task force developed the key resource constraint data on major nonenergy resource availability, such as labor, materials and equipments, finance, environment, transportation, and water, as well as an integrating model to "balance" this data; that is, to generate an equilibrium supply/demand solution.

Fig. 3.12. Project Independence Blueprint

SOURCE: Federal Energy Administration,
 "Project Independence Report, Project Independence,"
 Nov. 1974, p. 410.

Environmental Assessment. Some of the emissions and other environmental impacts for each level of production and consumption by region were modeled by this group. However, the model does not consider the sulfur content in coals, in different types of crude oil, and in other fuels.

International Assessment. This task force assesses the cost of vulnerability to embargoes under different scenarios and forecasted future world oil supply, demand, and prices.

Research and Development. The responsibilities are self-regulatory, though it is not clear whether any input from the R&D task force is used in the Project Independence model itself.

Policy Analysis. The major function of the Policy Analysis Work Group is to "identify and analyze various policy options and alternatives for the Project Independence Blueprint. The analyses considered the impacts of the policies on various sectors of the economy and on consumers. In particular, policies were analyzed for increasing domestic supply, reducing energy demands, decreasing risks of impacts of embargoes, and maintaining emergency plans for dealing with future supply cutoffs."¹⁰ Apparently this group has provided the bulk of the material that constitutes the Project Independence Report and has determined the eight major scenarios around which the model is based.

The Project Independence model's superstructure is shown in Figs. 3.13 and 3.14. Figure 3.12 shows the interrelationships -- in terms of the model itself -- of the various task forces described in the preceding paragraphs. The "integrating model" of Fig. 3.13 generates an equilibrium solution for the energy sector as shown in Fig. 3.14 and is discussed in more detail in the next section.

3.7.1 Model Comprehensiveness

The Project Independence model of the nation's energy system is probably the most comprehensive and all-inclusive energy model yet produced. This is not surprising, in view of the quantity of financial and manpower resources utilized in the development of this model. All possible sources of energy are included in the model. For each such source, detailed analyses

Fig. 3.13. The FEA Project Independence Evaluation System

SOURCE: Federal Energy Administration,
"Project Independence Report, Project Independence,"
Nov. 1974, p. 41.

Fig. 3.14. Schematic Diagram of the Project Independence Evaluation System

SOURCE: Federal Energy Administration,
 "Project Independence Report, Project Independence,"
 Nov. 1974, p. 416.

were performed to ascertain the potential supplies (at various prices), as well as the resource requirements necessary to produce these supplies. "Resource constraints were developed for 62 different manpower skill categories and about 30 types of materials and equipment where shortages might be expected."¹¹ Even though these constraints are included, they are not incorporated into the integrating model in terms of affecting the equilibrium solutions. The authors are aware of this deficiency, especially in not showing the impact of constraints to limit the development of energy supplies.

Illustrative of the level of detail of the model is the following description for the case of oil:

The production of conventional crude oil is described for fourteen regions at any of more than a dozen price and quantity levels, and includes three major by-products that also contribute to the supply system. Once oil is produced, it may be moved by a combination of pipeline, barge, or tanker route to any of the seven refining centers. When combined with other inputs, several refining technologies or yields must be selected in each refining center to determine the transformation of the crude oil into varying combinations of the four types of refined products. These products are shipped in turn by varying modes of transportation to the nine demand centers for final consumption or conversion to electric power. At each stage, the capacities of processing, transportation, and key resource inputs are taken into account. The level of activity of each variable must be determined simultaneously with the evaluation of all other fuel types and energy demands.¹²

Important in this analysis is the model's inclusion of the behavioral activities of the different decision-making units that are involved in delivering energy from the producer to the consumer.

The PIES model estimates energy demands for the residential and commercial, industrial, transportation, and utility sectors. Total energy demand by the residential and commercial sector is disaggregated into electricity and heating fuel (i.e., natural gas, distillate oil, residual oil, bituminous coal, etc.) with potential substitution possibilities among all of these sources of energy. The industrial sector is represented by 24 2-digit SIC industries. Substitution in this sector exists between electricity and boiler fuels (i.e., natural gas, residual oil, distillate oil, etc.), but no substitution with anthracite or bituminous coke is assumed. Potential energy demand in this sector is obtained with the assistance of an input/output table that measures the energy use per dollar of value added. The transportation sector demand

for energy is disaggregated by type of fuel, on the assumption of no substitution among these different fuels. The allocation of fuels for electrical generation is determined by a linear programming model, minimizing total costs of present and future plant capacity. Costs include fuel prices, capital equipment, interest charges, and system load factors. From the demand submodels projected, demand for electricity is determined from which peak, intermediate, and base load requirements are measured. Base load plants are able to use any of the fossil fuels, nuclear power, or hydro-power. The model assumes that 75% of all electricity generated is base load.

The PIES is essentially a model of the nation's energy system. Presently, though, much work is being done in improving the regional submodels, especially the Demand Forecast Model. As noted earlier, the various energy and fuel supplies are all determined on a regional basis, though the regions vary with each source. In the Project Independence Report, energy demands had been distributed regionally, based upon census regions. The latter was accomplished first by generating national demand levels, and then by distributing these among the census regions, apportioned according to current demands. Different growth rates for the various Census Regions were incorporated into these calculations, as were various data on past histories of the regional demands. Transportation between regions is incorporated into the model, but transportation within each region is not. Environmental effects are estimated at the Census Region level of detail.

The fact that the Project Independence Model actually consists of several independently developed submodels means that a great deal of flexibility exists to modify the overall model, since each submodel can be separately refined and tested. Moreover, this flexibility is enhanced even more because some of the submodels themselves are composed of several submodels. In fact, Project Independence is an ongoing activity, and several such model changes are under way.

3.7.2 Economic Aspects of the Model

The Demand Forecast Model is an econometric simulation model, which is a variation of a model developed by Data Resources, Inc., called the "Energy Policy Model." (A forthcoming report describing the model in detail is not yet available. Also unavailable at this writing is an EPA technical report describing the modifications of the Energy Policy Model that were incorporated into

the Project Independence Demand Forecast Model.) The model predicts quantities of energy demanded by each of the residential and commercial, industrial, and transportation sectors. In the residential and commercial sector, demand is explained by the housing stock, per capita income, and the price index for fuel and power. Market shares are explicitly considered by separating demand into electrical consumption and heating fuel. Electricity consumption is explained by electricity prices, heating fuel prices, and per capita income. The difference between the endogenously estimated total demand and electricity consumption is the heating fuel estimate. A market-share equation is then used to partition demand for heating fuels among the various products (i.e., natural gas, distillate, residual).

The demand model assumes that demands are dependent upon macro-economic variables (i.e., rate of inflation, industrial production, income), but that energy demand levels do not themselves "feed back" or affect these variables. This assumption is not realistic in the event of large changes in quantities of energy demanded, in which case the previously forecasted macro-economic and demographic variables must be adjusted. The authors stated that the approach of comparing these revised variables (as a function of the energy forecasts) with the arbitrary ones is "imprecise at best and can only highlight major inconsistencies."¹³ Also no second-round effects of the impact of the revised economic variables on energy parameters were taken.

The Demand Forecast Model utilizes a "lagged adjustment of demands to changing conditions" approach, in which "the demand functions have been formulated as distributed lag equations."¹⁴ This approach aims to model the fact that the types and amounts of energy demanded by a consumer (industrial, commercial, residential, or transportation) are to a great extent a function of equipment purchased on a long-term basis. Thus, responses to changes in the energy picture may occur slowly over time, which is a good feature of the model. The demand equations for the industrial and transportation sectors are dynamic, while the residential and commercial sectors are static. In the industrial sector, for example, long-run elasticities are formulated with respect to the price index for total fuel and power and to total potential demand for energy. Long-run elasticities were also developed in the transportation sector with respect to income and price of each fuel product. The elasticities are also assumed to remain constant during the time horizon.

Interfuel competition in the residential/commercial/industrial sectors is handled by use of a logit probability model that assumes the sum of the market shares equals unity. Market shares are a function of relative energy prices, and either time or the lagged value of the share. The industrial demand for energy is assumed to be a function of the price index for total fuel and power, and industry activity. The level of activity in specific manufacturing industries is determined through the use of input/output coefficients that calculate the potential industrial demand for each major fuel. Twenty-four manufacturing categories (2-digit SIC numbers) are used. These levels are then separated into demand for electricity and for boiler fuels (i.e., natural gas, residual, distillate), with electricity demand endogenously estimated. Again, the same type of market-share equation is used to partition boiler fuel demand into demand for the various products. The transportation sector demand includes demand for gasoline, liquefied gases, residual fuel, jet fuel, and bituminous coal. These components are explained by respective price, by per capita income, or by time. No substitution exists among the different fuel products.

As mentioned previously, nine fuel task forces developed supply curves for each fuel, as a function of prices. Supply curves were developed regionally, using the major producing regions of the country, which are different for each fuel. The regional curves took into account differing production costs, finding rates, potential recoverable reserves, transportation capacities and costs, and constraints on drilling of oil and gas. However, the method of incorporating drilling constraints in the analyses were not well documented.

The supply curves do not shift over time because technology changes and economies of scale are assumed to remain constant. One of the most serious shortcomings of the Project Independence Model is the lack of dynamics on the supply side. Presently there exist only lead time considerations in the construction of some facilities. No provision in the model "assures that a facility that is economic and feasible, hence built in 1980, continues to operate or is even in existence in 1985;¹⁵ nor, does the supply model analyze dynamics in the system in terms of estimating the time frame of attaining equilibrium after a change in one of the parameters. The model merely "yields snapshots of supply in a given year -- independent of its desirability in previous or future years."¹⁶ These negations are serious in that they could cause the market price forecasts to be biased.

As should be clear from the above discussion, the supply curves depend heavily on the specific assumptions made, which, in turn, are directly related to certain very specific policy actions. The model can use any mix of the "Business as Usual" and the "Accelerated Development" supply curves for conducting analyses.

The policy assumptions used in generating the "Accelerated Development" curves were somewhat restrictive in nature in that they did not, for the most part, attempt to study the impacts of radical changes in energy policy priorities. For example, in the solar energy curves, no consideration was given to an intensive R&D effort, supported financially on the same order of magnitude as that of current nuclear R&D funding.

All of the above supply curve assumptions are potentially correctable and many different ones could be incorporated into the model without too much difficulty, particularly since all of the current supply curves were independently developed.

Supply and demand estimates are reconciled in the Integrating Model, which

begins with estimates of the quantities demanded for fuels by each (census) region as a function of price, as specified by the demand group. It works through the transportation processing and distribution system with the Department of Transportation data, seeking a least-cost solution, using the supply price data provided by the resource groups, in order to discover what fuels are available by region. This first solution does not lead to an equilibrium, but it does make clear the direction in which prices and quantities must move to reach such an equilibrium. The model continues to repeat the process until an equilibrium for all fuels is reached for all regions. This equilibrium solution is the supply and demand... consistent by sector, fuel type, region of the country, and at a market clearing price.¹⁷

It represents a comparative statics framework in which the equilibrium values of energy prices and quantities are determined under postulated conditions with an evaluation of how these variables change as a result of changes in parameters.

The above supply/demand interactions are simulated using a large linear programming model that allocates energy to demand regions under the criterion of minimizing total energy costs for all of the regions as a whole. This framework not only provides a consistent method of displaying the flow

of energy between regions, but also identifies the interdependency of the different regions. In the PIES framework, the interdependency of the regions is measured not only in terms of suppliers of energy competing for specific markets but also in terms of the competition among the different demand areas for the purchasing of energy resources. Input to the framework includes supply transport costs, and quantification of certain output and transportation constraints, all of which are determined by the various task forces. Generally, the analysis of the interregional flow of a commodity is considered a programming problem that is quadratic if linear demand and supply functions exist, and if output is limited by the geophysical distribution of resources. Moreover, Samuelson¹⁹ proved that the solution of the linear programming model represents competitive equilibrium parameters. Since the energy industries are far removed from competitiveness, the output of the PIES model may overestimate energy output, or underestimate the delivered prices of the energy.

3.7.3 Model Capabilities

As indicated in Section 3.7.1, the Project Independence Model is quite comprehensive in terms of the supply sources, demand sectors, and alternative processing and transportation systems, which it includes, as well as in incorporating regional supply and demand differences. The model produces sufficient data output so that detailed analyses can be performed on such additional considerations as social and environmental effects, and the impact of any U.S. energy policy on the international energy situation.

For each fuel, potential production was estimated for 1977, 1984, and 1985, under two different sets of assumptions. In the first case, production was estimated under "Business as Usual" conditions, which assumes that there will be no changes in current tax policies, implementation of current environmental regulations, continuation of current energy research and development programs, and the elimination of the then current (1973-1974) price and allocation programs. The second case under which fuel supplies were estimated is under the assumption of an accelerated development strategy, which features various incentive programs (most of which would require Congressional approval to implement). The specific incentives and other programs to increase supply varied, depending on the particular fuel.

Although some projections beyond 1985 were made, these are, in general, considerably less thorough. For example, the impact of solar and geothermal energy in the Project Independence Model is minimal, because that particular task force felt that the necessary technology for large-scale use of these energy sources would not be sufficiently developed by 1985.

The PIES Model was developed as an evaluation tool for policy analysis and technology development. Environmental impacts, including air pollutant emissions and water pollution effluents, are estimated for each policy scenario simulation run.

A potential weakness in the Project Independence Model is the use of constant prices for crude oil over time. That is, to investigate any particular policy option using the model, one price for crude oil must be provided (usually \$7 or \$11 per barrel was used in the cases discussed in the Project Independence Report). Although provisions are made for varying the price of oil, the model assumes that world oil prices will determine U.S. energy prices and, in turn, have an impact on U.S. supply possibilities and rate of energy growth.

3.7.4 Summary and Conclusions

The Project Independence Energy Model has great potential as a tool in evaluating alternative energy sources at the national level. More importantly, the regional analysis is performed in a framework that allows for interdependency among the Census Regions. For example, the demand for energy in one region affects the price that other regions have to pay, since the market price for a fuel is dependent upon national demand. Moreover, one region's ability to import fuel from another region is dependent upon the demand of all other regions for that fuel. This interregional type of analysis is needed to indicate the competition existing among not only the selling but also the consuming regions.

Presently, the FEA is exerting much time and effort in using more sophisticated techniques in estimating regional variables (i.e., demand and supply availability). Demand forecasts will be estimated by econometric methods with explicit consideration of interfuel competition. On the supply side, work is needed to make the cost functions dynamic. Without the dynamics,

the forecasted market prices may be quite inaccurate. More work is also required in evaluating the social impact of pollutants, as well as in identifying potential transportation bottlenecks. Additionally, a great deal of attention should be paid to performing sensitivity analyses of the model by systematically varying the key assumptions incorporated and comparing the resulting outputs. Considerable testing must be done before this, or any other complex model, can be properly judged. Work is currently being done in this area. The need for consistency between the regional economic variables and the forecasted energy prices and quantities can be filled by using these forecasted values to revise the economic variables, which again are used to estimate the energy parameters.

Some general criticisms of the output from the model include the following: it understates capital requirements; excludes replacement, retrofit, and environmental costs; underestimates the market share of coal in the economy; acknowledges uncertainty only of the price of oil; disregards disruption in coal supplies and in the operation of nuclear power plants; and assumes no production constraints. Other criticisms of the Project Independence Model made by MIT faculty members are presented in Appendix C.

On the plus side, the PIES Model has the potential to analyze regional energy problems within an interregional framework. Further, its level of supply and demand detail provides an excellent base for conducting interfuel competition analyses. Since the model includes a macro-growth submodel, total energy demands can be linked to economic growth, and with proper feedback mechanisms, the effects of energy policy on growth can also be evaluated. Finally, the model has already been used for a number of policy analyses and potential technology changes. Therefore, the PIES model represents one of the most comprehensive energy modeling techniques available today.

3.7.5 Reference

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15. Ibid., p. 419.
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3.8 WISCONSIN ENERGY MODEL

The Wisconsin Energy Model (or WISE model) is being developed by the Energy Systems and Policy Research Group at the Institute for Environmental Studies, the University of Wisconsin, Madison. The work is sponsored by the Upper Great Lakes Regional Commission and the Research Applied to National Needs Program of the National Science Foundation. "The primary goal of the research group is the development of quantitative tools for energy policy analysis."¹

The WISE model uses the simulation mode of analysis. The program is built in modular form to facilitate model modifications and extensions. In their own words, the research group has "opted for a research approach that stresses flexibility and maximum room for innovations."² The main subcomponents of the system are the socioeconomic, primary energy source, end-use demand, electricity production, and environmental impact models.

The basic approach of the model is an engineering design approach incorporating projections of trends and energy intensiveness factors. The

primary driving parameters of the model are population, value-added, and other socioeconomic parameters. Integration is achieved by defining most parameters on a per capita basis; therefore, population is the main integrating parameter. However, in the modeling approach used, "maintenance of this internal consistency continually demands great attention."³ The problem of internal consistency and the inability to conduct most policy analyses are inherent difficulties associated with trend or parametric models, limiting the usefulness of the WISE model in its present form.

A flow diagram of the WISE model is presented in Fig. 3.15. In the top right section of the diagram is the energy supply portion of the model, which, except for electricity generation, is determined exogenously. "The supply component of the model is primarily data sets and subroutines by which the user can specify various scenarios describing the origin, availability, and price of various fuels that could be imported into Wisconsin."⁴ Therefore, the WISE model can be classified as a demand model. The implications of this and other characteristics of the model are discussed in the following sections.

3.8.1 Model Comprehensiveness

The model estimates the demand within the state of Wisconsin for coal, oil, natural gas, and electricity. Although built for Wisconsin, the concepts are transferable to any state or region. National estimates are also possible, using the WISE methodology.

Energy demands are independently estimated for the residential, commercial, industrial, agricultural, and transportation sectors. Residences are classified as single family, urban apartment, or rural households. The commercial sectors comprise retail and government activities. Industrial or manufacturing activity is disaggregated by 2-digit Standard Industrial Classification. The agricultural sector consists of crop and livestock activity and the transportation sector consists of auto, intercity mass transit, and freight activities. Primary fuel demands for electricity production are based on electricity demand estimates derived from the other sectors.

Energy demands are aggregated by sector, fuel type, or physical process. Some of the physical processes are space heating, air conditioning, lighting, appliances, production processes, and transportation. The model is being extended to classify energy demands spatially and temporally.

Fig. 3.15. WISE Model

In general, demands are estimated by projecting a driving parameter (e.g., value-added per capita) and multiplying it by an adjusted "energy-intensiveness" factor. An energy-intensiveness factor may be adjusted because of a policy or technology change. Trends have been used in most of the demand sectors to project the values of the driving parameters. In some cases, trends are used to estimate changes in the intensiveness factors. However, all of these factors can be specified by the user. To illustrate the methodology used in the WISE model, the following example is presented:

Future annual (commercial) energy demands are forecast from the product of population, per capita sales and expenditures, and the appropriate energy-intensiveness coefficients. In equation form, $EC_{j,t}$, the total consumption of fuel j in the commercial section in the year t is

$$EC_{j,t} = POP_t (CSPC_t \times EICS_{j,t} + GEPC_t \times EIGE_{j,t}) ,$$

where $CSPC_t$ and $GEPC_t$ are the per capita commercial sales and government expenditures, and $EICS_{j,t}$ are the corresponding energy-intensiveness values for fuel j in the year t . Trends in the intensiveness values are derived from historical data or specified by the user ... ⁵

The developers of WISE observed that the above model "proved to be quite limited in its capability to answer specific policy questions."⁶ Therefore, a physical process formulation based on end-use requirements was developed. This latter approach has been used for the commercial and residential sectors, but trends of the driving parameters are still an integral part of the entire WISE model.

The WISE model concentrates on the final demand and electric generation aspects of the energy system within the state of Wisconsin. But, the environmental impact submodel considers the entire energy spectrum from extraction through consumption. Environmental damages are identified as occurring within or out of state. The environmental model estimates the impact of various energy demand configurations, but does not have any feedback mechanisms to estimate the impact of environmental concerns on energy demand.

The main advantages of the WISE model are its simplicity, adaptability, and interactive, including graphical display, capabilities. As stated earlier, the modeling approach was designed for flexibility. Indeed the model is quite

flexible, though its reliance on trends limits its usefulness. This is particularly true now since past trends probably are no longer valid due to the large perturbations that have occurred in the energy market. Yet, since the user has the option to provide exogenously determined driving parameters rather than using trends, the model can be adapted to account for changing trends.

3.8.2 Economic Aspects of the Model

WISE is a noneconomic model. There is the possibility of incorporating energy substitutions through the energy-intensiveness factor by making them price-sensitive. However, this is not part of the present model. Rather, the "energy intensiveness is a surrogate for a large variety of items that affect energy use, such as level of output, marginal price of capital, labor, energy, and the process and technology involved."⁷

Furthermore, the model does not consider interregional competition for fuel. The supply of energy to Wisconsin is determined exogenously and is not sensitive to changes in the national energy market. Also, no direct feedbacks from energy usage to population and economic activity exist. Therefore, the growth of the region is assumed to be independent of the price and availability of energy. This assumption may have been reasonable in the past, but may not be true in the future.

3.8.3 Model Capabilities

The WISE model may be used to predict future energy requirements on a statewide basis provided past trends are valid, or the user can provide reasonable estimates of the driving parameters. Because feedback effects are not considered, i.e., the market response to policy or technology change, the model has limited use as a policy tool. The energy impacts of certain regulations, such as building codes that dictate a technology, may be simulated using WISE.

The model can best be classified as a trend or parametric model. The latter characteristic of the model allows the user to specify growth, energy-intensiveness factors, and other relevant physical parameters.

3.8.4 Summary and Conclusions

The WISE model's strongest attribute is its simplicity. This allows the user to obtain a reasonable understanding of the energy demand sector. Since the model does not consider market responses of each sector, the model's description of the demand sector is oversimplified. However, for a non-technical or noneconomic user, the model may be appealing.

If past trends are appropriate, the model would produce reasonable estimates of energy demand. This is particularly true for the short-run because of inertia in the system. Recent developments in the energy market, however, cast some doubt about the appropriateness of past trends.

If the energy-intensiveness factors or the driving parameters are made sensitive to policy or technology changes, the model could be used for policy analyses, especially for local policies. National changes in the energy market would require expansion of the supply aspects of the WISE model before they can be reasonably evaluated.

Because of the level of detail provided by the model, it can be a useful tool for microscale analyses; these include estimates of economic, social, and environmental consequences of energy policy. Effects of national energy policies must be proved exogenously, while some local regulatory policies can be simulated endogenously.

3.8.5 References

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4. COMPARISON OF EXISTING ENERGY MODELS

In Section 2, eight criteria were defined for reviewing the energy models. It is clear from the reviews that none of the models considered satisfy all of these desirable attributes. Unfortunately, a simple summary table identifying the criteria satisfied by each model cannot be constructed because some of the models only partially satisfy some of the criteria. Additionally, because the approaches used in the models differ, a comparison of models satisfying the same criteria becomes difficult. Finally, a complete evaluation of these models cannot be made without information on their accuracy, ease of use, computational efficiency, and other operating characteristics.

Although simple comparisons cannot be made, two summary tables have been constructed. These tables will facilitate discussion on the state of the art of energy models and identify areas of future research. Table 4.1 summarizes the economic aspects of the models, providing the approaches used and some of the primary data sources or driving parameters required to simulate the economic behavior within the model. Table 4.2 summarizes the comprehensiveness and capabilities of the models, identifying the principal independent variables used to drive the model when policy or technology changes are simulated. In addition, the types of perturbations that the model can simulate endogenously are listed.

Total energy demands are either provided exogenously or are estimated, using trends, econometric techniques, or input/output techniques. Energy consumption is usually assumed to be a function of GNP, income, population levels, production output, or other demographic-economic variables. Energy prices (or an energy price index) are used as determinants of energy demands in the Kalter, PIES, H-J, and EMSAS models. However, none of the models explicitly considers the impacts of energy costs on the general economy. The H-J model can account for energy price effects on the economy if the prices calculated in its interindustry model are fed back into its macro-growth model as a change in the price deflator factors.

The demand for energy will change as energy costs change due to both substitution and income effects. Most models do not separate these effects. Of particular importance is the income effect and its influence on the rate of growth of the economy. Since increases in energy costs will most likely

Table 4.1. Summary of Economic Aspects of Energy Models

MODELS	ENERGY DEMAND	ENERGY SUPPLY	INTERFUEL COMPETITION				INTERREGIONAL COMPETITION	
			Method	Market Logs (Dynamics)	Sectors	Fuel Prices	Method	Transportation Cost
Battelle Columbus - EPA Energy Quality Model	NPC's forecast for U.S. AQCR forecast taken from 1973 study by M.C. Cook Sartorius and Company Other exogenous sources	Stepwise supply function applying the "minimum acceptable selling price" concept No exploration	Linear Programming	Power Plants constrained to present fuel use capabilities	Electric Utilities	Minimum acceptable selling prices are provided exogenously and adjusted upward based on shadow prices obtained from LP model	Linear programming (Objective function minimizing total systems energy costs)	Rates provided exogenously
Baughman's Dynamic Energy System Model	Demand by sector provided exogenously	Parametric engineering supply functions Exploration activity provided exogenously	Log linear equation which is price sensitive (Partly econometric and parametric)	Total demand assumes that some consumers are "locked in" to particular fuel, i.e. demand for fuel is not price sensitive Supply model assumes exponential delay functions	Electric Utilities Residential/Commercial Industrial	Equals point on supply curve corresponding to a given demand for each fuel	Not considered	Assumes that costs are constant multiples of supply prices of each fuel
Brookhaven NL Models ● Basic	Exogenously provided from other studies, extrapolation, or user's assumption	Exogenously provided from other studies	None	Not considered	Not considered	Exogenous	Not considered	Rates taken from FPC 1970 National Power Survey Report
● Modified	Same as above	Exogenously provided elasticity of supply (presently set at .5)	Linear Programming	Assumes no fuel conversion until capital stock has reached a given age	By functional activities (end-use) of Residential/Industrial Electrical Utilities	Derived from exogenously provided supply functions and shadow prices of LF model	Not considered	Rates taken from FPC 1970 National Power Survey Report
Energy Management Simulation and Analysis System (EMSAS)	Based on trends or exogenously provided (for industrial sector, it can be estimated using price sensitive econometric equations)	Parametric engineering - simulation equations (oil, natural gas) Exogenous (coal) Exploration is price-sensitive, probability of success based on historical trends	Trend analysis Econometric Market share equation (Varies by sector)	Portion of demand is assumed to be market sensitive This portion is provided exogenously Gas and oil supply models allow for lag between time when they are committed to production	Industrial Residential (single unit homes) Electric Utilities	Future prices trended or provided exogenously	User determines inter-regional flow of energy	Rates provided exogenously
Hudson-Jorgenson Model (H-J)	Input-Output and Macro Growth Mode (technical coefficients and final demand components estimated by econometric equations)	Exogenously provided from other studies F.O. coefficients	Econometric equations	Macroeconomic model is dynamic Comparative statics	Agriculture, manufacturing, transportation, communications, coal mining, crude petroleum and natural gas, petroleum refining, electric utility, and gas utility as intermediate demand, and residential, government, and commercial as final demands	Market clearing prices dependent upon demand and supply conditions	Not considered	Not considered
Kalter's Parametric Model	Dynamic parametric equation	Dynamic parametric equation	Parametric equation (substitution occurs if fuel prices differ by fixed percentage)	Assumes short-run and long-run elasticities for demand and supply (with response rate)	All sectors simultaneously	Market clearing prices dependent upon demand and supply conditions	Not considered	Not considered
Project Independence Evaluation System (PIES)	Econometric equations	Modified NPC parametric equations used to calculate the "minimum acceptable selling price" by the discounted cash flow technique (oil, natural gas) Step function where price is the "average minimum acceptable selling price" (coal) Exploration activity for natural gas and oil is provided exogenously	Market share equation (linear logit) Linear Programming	Econometric demand models developed with long-run and short-run elasticities	Residential/Commercial Industrial (Market Share) Electric Utilities (Linear Programming)	Equals market clearing price where demand equals supply	Linear Programming (objective function minimizing total systems energy costs)	Rates provided exogenously or determined by Task Force
Wisconsin Energy Model (WISE)	Trend analysis Engineering, parametric models User defined	Exogenous	Assumed change in energy intensiveness coefficients (Industrial) Assumed mixes of fuel (Electric Utilities)	Explicit consideration of age of capital equipment	Industrial Electric Utilities	Published prices from various sources	Not considered	Not considered

Table 4.2. Summary of Energy Model Comprehensiveness and Capabilities

MODELS	SPATIAL	SUPPLY	DEMAND	POLICY		TECHNOLOGY	
	Level	Fuels	Sectors	Type	Independent Variables Affected	Type	Independent Variables Affected
Battelle Columbus - EPA Energy Outlook Model	92 Supply districts of fuels 233 AQCR demand region	4 grades of coal by sulfur content Natural gas Distillate and residual oil	Residential/Commercial/ Industrial Electric Utilities	SO ₂ regulations	Supply availability Control costs	Power plant SO ₂ Controls Fuel production technology improvements	Control costs Fuel prices
Baughman's Dynamic Energy System Model	U.S.	Coal Natural gas Oil Nuclear Hydro	Residential / Commercial Industrial Transportation Electric Utilities	Directly affecting price (e.g., tax, tariff)	Price	Directly affecting price	Price
Brookhaven NL Models • Basic	U.S. N.Y. City	Coal Natural gas Oil (distillate, residual, jet-fuel, gasoline) Nuclear Hydro	Residential Commercial Industrial Transportation (by end-uses) Electric Utilities	Parametric reduction of appliance or boiler efficiencies	Efficiencies	Parametric changes	Technology Trajectories
• Modified	U.S.	Same as above	Same as above	Environmental regulation Directly affecting price	Constraints Price	Directly affecting cost	Price
Energy Management Simulation and Analysis System (EMASAS)	State (Industrial demand) Census Region demand Supply estimates on national basis which are allocated to "fuel districts"	Coal (only utility usage) Natural gas Oil Nuclear Hydro	Residential/Commercial Industrial (2-digit SIC) Electric Utilities Natural gas feed stocks	SO ₂ regulation Directly affecting price (e.g., tax, tariff)	Price Control Costs	Directly affecting price Sulfur control technology	Price Costs
Hudson - Jorgenson Model (H-J)	U.S.	Coal Natural gas Petroleum Nuclear Hydro	9 intermediate sectors Personal consumption Government Investment Exports	Directly affecting price (e.g., tax, tariff) Directly affecting macroeconomic variables	Energy price Real income	Directly affecting price	Price Productivity Real income
Kalter's Parametric Model	U.S.	Coal Natural gas Oil	All sectors simultaneously	Directly affecting price (e.g., tax, tariff)	Price	Directly affecting price	Price
Project Independence Evaluation System (PIES)	U.S. and Census Region Demand Supply districts of fuels	Coal Natural gas Oil Nuclear Hydro Synthetic fuels, Solar and Geothermal	Residential/Commercial Industrial (2-digit SIC) Transportation Electric Utilities (some end-uses)	Directly affecting price (e.g., tax, tariff)	Price	Directly affecting price	Price
Wisconsin Energy Model (WISE)	State of Wisconsin	Coal Natural gas Oil (distillate residual, kerosene, LPG, gasoline) Nuclear Hydro	Residential Commercial Industrial (2-digit SIC) Transportation Electric Utilities Agriculture (by end-uses)	Parametric change in engineering efficiency Regulations such as building codes	Energy intensiveness coefficients	Changes in engineering efficiency	Engineering parameters used in demand sub-models

increase the costs of many other commodities, the buying power of the consumer will be reduced. If this reduction is significant, it will result in a slowing down of the economy, reducing the derived demand for energy and tending in turn to reduce energy prices. Therefore, if the income effects are not properly accounted for, a model could overestimate demand and the price of energy. This is an area in which the state of the art could be improved.

The factors that determine the supply of fuels, such as the levels of reserves, development and production costs, and exploration activities, are not explicitly considered in the Energy Quality, BNL Basic and Modified, H-J, Kalter, and WISE models. Although all of these models assume that supply will be sufficient to meet demand, the WISE and Basic BNL models do not relate supply to fuel prices. The other models listed above simulate the response of supply to price parametrically rather than econometrically. In general, these models implicitly account for changes in supply by variations in fuel prices, a minimum acceptable selling price, the ratio of reserves to production, and/or I/O coefficients. Some of these variables, however, are provided exogenously as indicated in Table 4.1.

Additional comparisons are that: the Baughman, EMSAS, and PIES models explicitly consider the effect of exploration and development on future production of energy resources; the Baughman and PIES models exogenously determine exploration activity levels; and EMSAS estimates the impact of prices, and other variables, on exploration activity for oil and natural gas, using historical relationships and parametric analysis.

Electricity supply determinants are considered in all of the models except the Basic BNL and Energy Quality models. The other models estimate the demand for electricity and then assume that production capacities will be increased to meet this demand. The PIES Model incorporates an LP model that chooses the least-cost combination of existing and incremental plant capacity to meet the demand for electricity. Although these models estimate electricity demands as a function of the prices of electricity and other fuels, only the H-J Model considers the effects of fuel prices on the price of electricity.

As indicated in Table 4.1, only the WISE and the Basic BNL models do not consider interfuel competition. The most popular approaches for simulating interfuel competition are econometric techniques and linear programming. The primary variables used to determine market shares are fuel prices, which are

provided exogenously or based on trends in the EMSAS Model. The other models that consider interfuel competition generate fuel prices endogenously through the supply and demand interface. The interfuel competition aspects of some of the models are restricted to a few sectors as shown in Table 4.1. Although Kalter's model considers all economic sectors, the model calculates only aggregate market shares; i.e., the market shares within each sector are not calculated.

A common problem in analyzing the dynamics of interfuel competition is accounting for market lags. These occur, in part, because capital equipment is often replaced when one form of energy is substituted for another. The choice between fuels must, therefore, include consideration of the capital replacement costs in addition to fuel prices. None of the models reviewed explicitly simulate the capital replacement decision. Most of the models account for market lags by separating demand into fixed and market-sensitive components in which the fixed component is a function of the characteristics (usually age) of capital stocks, or by estimating long-run demand elasticities, which implicitly account for these lags. Lags on the supply side are simulated using long-run elasticities, delay functions (e.g., exponential), or parametrically defined delays in production. Because of the importance of market lags in forecasting future energy demand and supply, more emphasis should be devoted to this problem.

Another area in which the existing models could be significantly improved is in dealing with interregional competition. Only the Energy Quality, PIES, and EMSAS models are multiregional. The Energy Quality Model is limited, because it considers competition between suppliers independent of demand. EMSAS, although regional, does not consider interregional competition. Therefore, only the PIES model attempts to simulate the effects of interregional competition from both the demand and supply sides.

Interregional competition is modeled in the PIES and Energy Quality models by using linear programming to minimize the delivered price of fuels. The key parameters in the model are transportation costs. The PIES Model allows for different modes of transportation for each fuel. The Energy Quality Model assumes that only one mode of transportation will be used for each fuel.

The most common levels of regional detail are the nation and census regions. The EMSAS model does estimate industrial energy demands for each state and the Energy Quality Model has a substate level of detail. The primary deterrent to regionalization is the lack of region-specific data. Some model structures, however, are more conducive to regionalization than others, because of their relative simplicity or less restrictive data requirements. Econometric and parametric models, such as the Basic BNL, Kalter, WISE, Baughman, PIES, and EMSAS models, are the easiest to regionalize. That four of these models have been used on a regional level exemplifies this fact. However, these techniques are not as conducive to modeling interregional flows of energy. Since this is primarily a transportation problem, a linear programming formulation, as used in the Energy Quality and PIES models, seems appropriate. The most difficult models to regionalize are those that use input/output analyses. These are the H-J and the Modified BNL models. Therefore, before these approaches are adopted for regional studies, the advantages of using I/O must be weighed against the difficulties (data acquisition, model efficiency, etc.) of regionalization.

Because of the selection process used to identify models, most of the models surveyed have good fuel supply detail. Except for EMSAS, all of the models consider coal, oil, and natural gas as primary fuels and electricity as a secondary source of energy. EMSAS has a strong natural gas bias but does consider oil, coal, or electricity for some sectors. The weakest aspect of the model is related to coal.

On the demand side, very few of the models are complete. The three demand sectors missing most often are the transportation, fuel oil and natural gas feed-stock, and agricultural sectors. The H-J model considers most sectors, but the industrial sector is not sufficiently detailed. The EMSAS, PIES, and WISE models have good industrial (2-digit SIC) detail. EMSAS provides for natural gas feed-stock demands; the BNL and WISE models have the best, and PIES has some end-use detail.

Although many of the authors claim their models to be useful for evaluating energy policies or technology changes, these claims are often overstated. If the effects of a policy on fuel prices, costs, and availability, or on technology changes are known, then some of the models can be used to

estimate the ramification of these changes on the energy system. Only the Battelle-EPA and EMSAS models have subcomponents that simulate the effects of policy on these key parameters. The Battelle-EPA Model is limited to sulfur dioxide regulations of fuels. The EMSAS Model considers sulfur dioxide regulations and also has provisions for simulating the impacts of new technology. Most of the models, however, are capable of analyzing the impacts of policies that directly affect energy prices such as taxes and price regulations. Others can simulate the effects of policies parametrically. The models with the least evaluative capabilities are the Basic BNL, Kalter, and WISE models. These models can be used only to conduct parametric studies and some regulatory policies. Yet, with sufficient modification, the BNL and WISE models can be quite useful because of their greater end-use detail.

This section has summarized the characteristics and approaches of the energy models reviewed and identifies areas where future research would be profitable. This information is used in the next section, where specific recommendations are made.

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5. RECOMMENDATIONS

The purpose of this review of energy modeling techniques is to provide direction for the energy budget analysis being conducted as part of the ERDA/DBER-funded Regional Studies Program. The approach taken is to build upon previous work to avoid duplicating the efforts of others and to provide direction for our research efforts on improving energy supply and demand analysis techniques. Therefore, the recommendations presented in this section are divided into two broad categories: Acquisition and Implementation of Existing Energy Models and Improvement of Energy Modeling Capabilities.

This review should clearly indicate that none of the existing energy models is capable of evaluating all of the present energy issues. Furthermore, development of a tool of that degree of comprehensiveness is not recommended. To begin with, the task may be impossible. Even if it were possible to simulate the impacts of all existing energy issues, it is unlikely that all future issues could be evaluated with the model. In addition, a large comprehensive model designed for multipurpose use would most likely not only be economically inefficient but its very complexity would make more difficult the interpretation of its results.

Rather than developing a single multipurpose energy model, we recommend that a library of techniques be developed and maintained. In this way, the analyst will be able to select the technique that best fits his present needs, thus avoiding excessive data collection, computer, and analytic costs.

For the Regional Studies Program, this library should consist of two general classifications of models. The first class, which is referred to as "local impact models," would provide a great deal of detail on end-use demands for energy; production processes of supplies; and/or environmental, social, political, and economic impacts. These models would be applied to state or substate areas. Energy requirements under a given national policy or technology scenario would be provided exogenously to these models. The function of the microscale models would be to simulate the impacts of decisions that only affect local markets, and to estimate the impacts of national policy or technology changes at the local level, where it has the most meaning.

The second class of techniques, which is referred to as "national synthesis models," would be designed to estimate energy supplies and demands as a function of decisions that affect the national energy market. These techniques should be multiregional and should include the entire domestic energy market with at least the Census Region level of detail provided.

These two classes of models could be coupled in a number of ways. As suggested above, the national synthesis models could provide regional energy supply and demand estimates consistent with national goals and policies and consistent with each other. That is, the output of the national synthesis models would be used as inputs to the local impact models. If, however, a regional policy were expected to have an impact on the national energy market, then the output of the local-impact models would be used as inputs into a national synthesis package to estimate the implications of local policy on the national energy market. In other words, the models could be used in conjunction with each other as the problem being analyzed dictated.

With these concepts in mind, recommendations for future work for the energy budget team at Argonne are presented below.

5.1 ACQUISITION AND IMPLEMENTATION OF EXISTING MODELS

Three of the eight models reviewed have been applied on a state or substate basis. These are the WISE, Basic BNL, and Energy Quality Models. The first two are similar in scope and, therefore, a commitment to one should be made although features of the other may be used.

Because of the superior evaluation capabilities of the WISE model, we recommended that this technique be incorporated into the Argonne energy system simulation library. The model has excellent end-use detail and includes engineering design parameters, which make it a good technique for evaluating local regulatory policies such as changing building codes. The interactive capability of the WISE model, including the graphical display and the environmental impacts model, makes it particularly useful for parametric analysis of regional energy technology options. The model could be extended to include measures of the social and economic impacts of energy systems, thus providing a capability for assessing impacts on a state-by-state basis. Before the WISE model can be used for many states throughout the country, however, it must be modified to include more details in the supply sector. To accomplish

this, the supply component of the Basic BNL model and other state energy models should be evaluated.

The data base of the Basic BNL model is excellent and determination should be made as to whether this feature can be utilized by the WISE system. Until further development of BNL's models are completed, recommendations beyond those indicated above are not warranted.

For evaluating the impacts of alternative sulfur dioxide regulations for power plants throughout the country, the Energy Quality Model is an excellent tool. It can be used to estimate the demands for low-sulfur fuels that will be satisfied by each supply district. It may also be a useful tool for estimating transportation, strip mine reclamation, and/or gasified coal requirements. Therefore, we recommend that the Battelle-EPA model be acquired.

In response to these recommendations, discussions with members of the Institute for Environmental Studies at the University of Wisconsin in regard to transferring their model have occurred. Similarly, arrangements are being made with Brookhaven National Laboratory to obtain their Reference Energy System Data Base, and with the Federal Power Commission and U.S. Environmental Protection Agency to obtain the Energy Quality Model.

Of the five national synthesis type models reviewed, only two generate regional estimates, are readily available, have existing data bases, and are relatively easy to adapt to the Regional Studies Program. These are the PIES and EMSAS models.

We recommend that the PIES model be acquired and made operational for use in the Regional Studies Program. PIES is more comprehensive than EMSAS, in many respects more theoretically sound, and it satisfies more of the criteria used to evaluate the energy models in this study.

Initial discussions with the Federal Energy Administration have been conducted and preliminary steps have been made to acquire the PIES model and its associated data base.

5.2 IMPROVEMENT OF ENERGY MODEL CAPABILITIES

This review should make evident that existing energy models are deficient in two important areas: (1) consideration of interregional competition and (2) integration of energy supply and demand forecasts with economic

growth. None of the models reviewed is truly multiregional, i.e., competing supply region interactions and competing demand region interactions are not considered. The PIES model is closest to having this capability. Regarding the latter point, the effects of energy prices on economic growth are not considered in any of the models, and only a few provide for the effects of energy prices on total energy demands. The most advanced model in this respect is the Hudson-Jorgenson model. Future work on energy modeling should concentrate on these issues.

Some of the models provide insight into the approaches that might be appropriate for extending the energy modeling state of the art. The methodologies used and a brief discussion of their principal strengths are discussed below. Then some suggestions are made concerning the development of an energy model that would incorporate all of the strengths of existing models, have the capability of simulating interregional competition, and integrate the energy system with the entire economic system.

Four principal methodologies are recommended for conducting part of the energy analysis: (1) linear programming, (2) input/output analysis, (3) econometrics, and (4) parametric analysis.

1. Linear programming (LP).¹ This is principally an allocative or an optimization tool. It has been proved useful in energy studies, especially in dealing with the problems of interregional allocation of fuels, i.e. the interregional transportation of fuels with a minimum cost objective, and regulatory policies on energy supply and demand.

2. Input/output (I/O) analysis. There are many useful applications of input/output analysis in economic studies.² Extension of the use of I/O to energy problems has been tried and the analysis has proved useful in answering specific energy problems.³ Input/output energy matrices have also been developed, and Appendix B describes the work done by Herendeen in this regard.⁴

Several basic problems are confronted when one tries to apply I/O analysis to regional energy studies. At the present time, no state or regional I/O tables that cover the entire U.S. are available. Not only is it costly to build regional I/O tables, but the data necessary to build them are not always available. Flows of commodities between regions make the problem

harder. Attempts have been made to derive the regional I/O coefficients from the available national coefficients, but care should be taken when using regional I/O tables that have been derived from national tables because they do not take into account many important regional differences. They do, however, consider variations in industrial mix, and represent a possible starting point for determining whether the cost of developing regional tables from local data is justified.

Input/output analysis has been shown to be a useful tool for short-term forecasting. The definition of "short-term" here is the length of time in which relative prices of inputs and outputs and technology do not change. The assumption of constant relative prices and technology hampers the use of this approach for long-term forecasts. Attempts have been made to incorporate the effects of technology changes into I/O coefficients,⁵ but the effects of price changes cannot be examined by the input/output technique itself. The chief advantage of I/O is its ability to simulate interindustry transactions and to integrate the energy system with the entire economy. Using techniques similar to those of Hudson and Jorgenson, or the Modified BNL models, I/O coefficients can be made price-sensitive and, therefore, more applicable to long-range forecasting.

3. Econometric Analysis.⁶ Econometrics is the application of statistical techniques to describe economic behavior. With very few exceptions, all the energy studies done so far have employed econometric methods in one way or another. This may be due to the fact that the econometric approach is flexible in that its use is not limited and/or restricted by specific theories, scope of study, or structure of the system. It is also flexible in the sense that the degree of specification and accuracy can always be adjusted, providing there is adequate budget and manpower. Further, econometrics can be combined with other techniques, such as LP and I/O, resulting in a very powerful, as well as flexible, evaluative tool.

The usefulness of econometric techniques is limited by the availability of data and the appropriateness of past statistical relationships for the future. Econometrics, like trend analysis, assumes a continuation of past relationships into the future. If future changes in the independent variables are similar to those that occurred in the past, there will be more reason to believe that the econometric equations derived are appropriate. However, for large changes in the independent variables, such as the recent

increases in energy prices, care should be taken in applying econometric techniques. For this reason, a purely econometric model may not be appropriate for long-run analyses.

4. Parametric Analysis. Parametric analysis is an approach by which the structural mechanism or system of an economy (or other phenomena) is hypothesized and through changes in this structure or its key parameters, system responses to outside stimuli are simulated. This approach is no less flexible for application to the regional energy studies than any other, and several of its advantages can be illustrated. First, its use is not restricted by the specification of model forms, often faced in the conventional econometric approach. Second, when not enough data are available for the statistical estimation of parameters of econometric models, this approach can still be used. Third, it is more flexible than the econometric approach in incorporating into the model such considerations as alternative assumptions, policy alternatives, dynamic characteristics, and recursiveness.

The approach recommended for constructing a multiregional energy supply and demand model is one that incorporates systems simulation, which combines each of these four methodologies into a unified structure. In this model, I/O will be used to integrate the energy system with the entire economy, and LP will be used to analyze interregional competition. Econometric techniques will be used for making the I/O coefficients dynamic, simulating interfuel competition, and estimating economic growth. Parametric analyses will be used to estimate the model's sensitivity to key parameters or to structure model components that are not well defined. Figure 5.1 depicts the structure of the model. The major components of the system are discussed in more detail below. These five components are: demand for final goods, demand for intermediate energy goods, supply of energy goods, interregional energy markets, and price feedback.

1. Demand for final goods. A major component of the demand for energy is induced demand. Thus, it is necessary to estimate the final demand for energy and nonenergy commodities in order to estimate total energy demand, which is the sum of final and intermediate uses of energy.

The first problem faced at this stage of the model formulation is to specify the degree of aggregation for the analysis. The level of aggregation

Fig. 5.1. Proposed Regional Energy Budget Modeling Approach

that is needed for commodities and prices will determine the level of aggregation of the input/output table required. If commodities or sectors are disaggregated to a level that is too finely detailed, the estimation for the final demands will be too complicated to be handled, and the availability and collection of data at that level will not be guaranteed. On the other hand, if the level of disaggregation is not fine enough, the estimation may be too gross to be meaningful, especially for policy analysis. Tradeoffs need to be made for the level of disaggregation. However, the approach used by Hudson and Jorgenson of collapsing the problem into only a few categories for some analyses, and expanding it again for others, may prove to be a valuable one for this stage of the analysis.

An econometric model is suggested to estimate final demands. For example, the model may be specified as follows:

$$D_i(t) = f(P_i(t), P_j(t), Y(t), PO(t), T, E), i \neq j, \quad (1)$$

where

- $D_i(t)$ $\equiv$ final (consumer) demand for the i th good at time t ,
- $P_i(t)$ $\equiv$ price of the i th good,
- $P_j(t)$ $\equiv$ price of the j th good, which is a substitute for the i th good,
- $Y(t)$ $\equiv$ income,
- $PO(t)$ $\equiv$ population,
- T $\equiv$ trend variable explaining changes in tastes, and
- E $\equiv$ disturbance term.

The number of the subscript i should be so determined that it can be matched with the number of products in the regional input/output table. Growth of income and population are determined in a macro-growth model, or provided exogenously. Estimation of these variables is easily obtained from public data sources. The work being conducted at Oak Ridge on population migration patterns as part of their Regional Studies Program may also be quite useful for generating these driving parameters. The prices of the commodities will be generated later in the system as a function of energy prices and other factors.

2. Demand for intermediate energy goods. The input/output framework is quite suited for estimating intermediate good demands. Lawrence Berkeley Laboratory or Karen Polenski's group at MIT could prepare an updated version of the regional input/output tables for the U.S. These tables could be used for energy demand estimation at the state or regional level.

The regional input/output coefficients can be converted into energy-output coefficients using Herendeen's method (see Appendix B). For this model, the conversion should be made for individual energy types. The multiplication of the estimated demands for final goods and the converted energy-output coefficients will give us total demand for energy by energy types.

This relationship can be expressed in a functional form as follows:

$$D_{r,k}(t) = g(a_{k,i}(t), D_i(t) \quad \forall i \mid P_j(t) \quad \forall j, T(t)) , \quad (2)$$

where

- $D_{r,k}(t) \equiv$ demand for the k th energy type at time t , in region r ,
- $a_{k,i}(t) \equiv$ energy-output coefficients for the k th energy types,
- $D_i(t) \equiv$ final demand for commodities as estimated in equation 1,
- $P_j(t) \equiv$ price of the j th energy, and
- $T(t) =$ technology at time t .

As can be seen from Equation 2, the demand for the k th energy type depends on the present energy-output coefficients and the estimated final demands given prices of energies and technology.

Various methods have been suggested to update the I/O coefficients and to estimate the future changes of the coefficients due to technological improvements.⁷ Changes in the relative prices of substitutable inputs will also cause the I/O coefficients to change. In the Hudson-Jorgenson model, prices and I/O coefficients are simultaneously determined. The current work on the Modified BNL model is also addressing this issue. The BNL model uses LP to adjust the I/O coefficients. In this model, the energy-output

coefficients will be adjusted using the following relationship:

$$a_{k,i}(t) = h(a_{k,i}(t-1), \frac{P_k(t)}{P_j(t)} \quad \forall j, P_1(t), P_c(t), K(t)) \quad k \neq j, \quad (3)$$

where

$$\begin{aligned} P_j(t) &\equiv \text{price of substitutable fuels,} \\ P_1(t) &\equiv \text{cost of labor service,} \\ P_c(t) &\equiv \text{cost of capital service, and} \\ K(t) &= \text{capital stock.} \end{aligned}$$

The variables $P_1(t)$, $P_c(t)$, and $K(t)$ may be generated by an auxiliary model or provided exogenously.

Equation 3 indicates that the energy-output coefficients at time t will be recalculated based on previous values of the coefficients, the relative prices of fuels, costs of labor and capital, and existing capital stocks.

Using this formulation, interfuel competition is simulated for intermediate goods by altering the I/O energy coefficients. Substitution between energy and nonenergy input products is also possible with this model formulation. Changes in technology are included in the model in the "T" variable. These may represent new, or changes in, I/O coefficients for specific technology advances or a smooth long-run technology-change estimation parameter.

3. Supply of energy goods. Supply of fuels is principally a function of prices of fuels, prices of inputs, amounts of reserves, and technology. That is:

$$S_{r,j}(t) = \bar{F}(P_j(t), P_1(t), P_c(t), R_{r,j}(t), T(t)) , \quad (4)$$

where

$$\begin{aligned} S_{r,j}(t) &\equiv \text{supply of the } j\text{th fuel in region } r \text{ at time } t, \text{ and} \\ R_{r,j}(t) &\equiv \text{amount of reserve of the } j\text{th fuel in region } r; \end{aligned}$$

and other notations and subscripts are the same as those in Equations 2 and 3.

Two methods are available for the supply analysis. Both of them estimate supply of fuels based on optimizing behavior of fuel producers given

prices of outputs, prices of inputs, and technology of production. One is the linear programming analysis and the other is marginal analysis. The results of both of the techniques are equivalent.⁸

4. Interregional energy markets. The demand and supply of fuels estimated separately in the above sections will be reconciled in the interregional energy market component of the model. The primary problem to be solved in this component is the solution for equilibrium prices of fuels in all regions.

Complications arise in the determination of equilibrium prices of fuels due to several factors: (a) many of the fuel prices are determined in the national or international market rather than in regional markets, (b) price of some fuels such as natural gas is regulated by the government, and (c) many energy markets, such as electricity, are not competitive. These factors should be included explicitly in the model.

Without considering these factors, a simple price determination formulation can be made as follows:

$$\frac{dP_i(t)}{dt} = \bar{g}(S_{r,i}(t) - D_{r,i}(t)) , \quad (5)$$

that is, a change in the price of a particular fuel is a function of the difference between demand and supply of that fuel. The demand and supply of each fuel type are determined by previous equations.

Other factors affecting the determination of prices of fuels can be considered explicitly, which leads to a formulation of:

$$\frac{dP_i(t)}{dt} = \hat{g}((S_{r,i}(t) - D_{r,i}(t)), P_{n,i}(t), I(t), P(t)) , \quad (6)$$

where

- $P_{n,i}(t)$ $\equiv$ price of fuel i in the national or international market,
- $I(t)$ $\equiv$ institutional factors, and
- $P(t)$ $\equiv$ policy vectors affecting price determination of fuels.

The flow of fuels between interregional markets can be determined as a function of price difference between the markets:

$$FI_{i,r}(t) = \bar{h}((P_{r,i}(t) - P_{n,i}(t)), T_{r,n}(t)), \quad (7)$$

and
$$FE_{i,r}(t) = \hat{h}((P_{n,i}(t) - P_{r,i}(t)), T_{r,n}(t)) , \quad (8)$$

where

$$\begin{aligned} FI_{i,r}(t) &\equiv \text{imports of the } i\text{th fuel to region } r, \\ T_{r,n}(t) &\equiv \text{transportation cost between region } r \text{ and} \\ &\quad \text{all other regions } n, \\ FE_{i,r}(t) &\equiv \text{exports of the } i\text{th fuel from region } r. \end{aligned}$$

Thus, the total demand and supply of energy in the region at time t will be:

$$D(t) = D_r(t) + FE_r(t), \quad (9)$$

and
$$S(t) = S_r(t) + FI_r(t) , \quad (10)$$

where

$$\begin{aligned} D_r(t) &= \sum_{i=1} D_{r,i}(t), \\ FE_r(t) &= \sum_{i=1} FE_{r,i}(t), \\ S_r(t) &= \sum_{i=1} S_{r,i}(t), \text{ and} \\ FE_r(t) &= \sum_{i=1} FI_{r,i}(t). \end{aligned}$$

5. Price feedback. The energy price vectors determined in the above equations will be fed back into the final goods demand, intermediate energy goods demand, and supply of energy goods components. Quantity readjustments and fuel substitutions will be made in this process. All of these readjustments and substitution processes will follow the same steps described above, in 1 through 4.

One additional factor that must be considered explicitly at this stage is the reformulation of prices of nonenergy commodities to determine demands for those commodities. The price determination of nonenergy commodities in general is a very complicated process. However, for this analysis, it is only necessary to reformulate the changes in the prices of nonenergy commodities as a function of changes in the energy prices; that is:

$$P_{ne,k}(t) = \hat{f}(P_{ne,k}(t-1), \Delta P_{e,i}(t))_{i=1,,n}, \quad (11)$$

where

$$\begin{aligned} P_{ne,k}(t) &\equiv \text{price of the } k\text{th nonenergy commodity at time } t, \\ P_{ne,k}(t-1) &\equiv \text{price of the } k\text{th nonenergy commodity at time } t-1, \\ &\text{and} \\ \Delta P_{e,i}(t) &\equiv \text{changes in the prices of energy goods.} \end{aligned}$$

The formulation of prices of nonenergy goods, using Eq. 11, is the simplest case where it is assumed that the changes in the nonenergy prices are explained only by the changes in energy prices utilized to produce those commodities. Equation 11 can be modified so that other factors would also be incorporated. Assuming that industries adopt marginal pricing, the following function can be posed for the determination of nonenergy prices.

$$P_{ne,k}(t) = \tilde{f}(P_{ne,k}(t-1), \Delta P_{e,i}(t), \Delta P_1(t), \Delta P_{in}(t)), \quad (12)$$

where

$$\begin{aligned} \Delta P_1 &\equiv \text{changes in prices of labor services, and} \\ \Delta P_{in}(t) &\equiv \text{changes in prices of other inputs.} \end{aligned}$$

The price relationships for I/O analysis might be useful for determining the impact of energy price changes on the prices of all commodities. Possibly the procedure used in the EXPLOR package developed by Pacific Northwest Laboratory⁶ would be useful for this phase of the model.

Since these price changes are fed back into the final demand determination component of the model, that is also a function of income, the total demand for energy has been determined such that both the substitution and income effects are considered. Additionally, the prices of energy would directly

affect total demand for goods and services, and thus can be made a determinant in estimating economic growth. The model structure therefore satisfies all of the criteria set forth in Section 2, and would considerably improve the state of the art of energy modeling by explicitly considering interfuel competition in a multiregional framework, and also by coupling the energy system to the rest of the economy.

5.3 REFERENCES

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APPENDIX A. Selected Comments on the Energy Model Reviews

Battelle Columbus - EPA Energy Model

Enclosed are my comments on your review of the Battelle-EPA Energy Quality Model. This review provides an excellent discussion of the model's capabilities as well as its shortcomings. However, because this review is based on the Chilton and Jimeson paper, it does not reflect the major computational changes incorporated in the model by EPA. These changes were initiated by our desire to correct the problems of poor convergence and long solution times which were associated with the Battelle version of the model.

We first developed a new matrix generator which builds a compact matrix, deleting all non-active rows and columns, and outputs the matrix in standard linear programming format. The Battelle DECOMP procedure was then replaced with the IBM MPS/360 system. (MPSX or UNIVAC's FMPS may also be used.) As a result of these modifications, solution times were reduced by a factor of 5 or more. Other benefits from the MPS formulation of the model include:

1. Optimality is proved in all cases (where feasible). This was not the case with the Battelle DECOMP code.
2. Sensitivity analysis is available with this system.
3. The model may be restarted from an earlier stopping point or even an earlier problem.
4. The user has great flexibility in modifying the current problem. New constraints, RHS's, or even new regions may be added to the current problem.

Additional constraints and activities, new transportation costs, and a new report writer have also been added to the model.

Warren P. Freas, Statistician
Control Simulation Section
Source Receptor Analysis Branch
U.S. Environmental Protection Agency

Baughman's Dynamic Energy System Model

No one is more aware of the limitations of the model you reviewed... than I. I think in general your criticisms were well founded. I do want to point out, however, that the work you reviewed was done in 1971-1972 and is significantly out of date. Your major criticisms:

1. that total demand is "inelastic" has received much additional work. We have estimated econometrically (from a time series of cross-sectional data for the U.S.) total energy demand functions as well as a set of fuel-split (market share) relationships that we now use.

2. that the model is "national in scope" has also received much attention in our work post-dating 1972. We have regionalized the model in four sections, including:

- a. residential-commercial demand; now treated at the state-level of aggregation (48 states and D.C.),
- b. industrial demand; also now treated at the state-level of aggregation (48 states and D.C.),
- c. electricity supply, now handled separately for the nine census regions of the U.S.
- d. coal supply, now based on four regional supply functions (Western, Mid-western, Appalachian underground, and Appalachian surface).

3. that the model is "not a planning model" is still true, indeed it was and is not an optimization model. However, I do not feel that this in itself detracts from its usefulness as a policy analysis model. In some cases it may even make it more useful.

In conclusion, I appreciate the chance to comment on your review.

Martin L. Baughman, Research Associate
Energy Laboratory
Massachusetts Institute of Technology

Brookhaven National Laboratory Energy Models

Attached is a summary of comments made by myself and other members of the staff which I hope you will find helpful. It was felt that many of your criticisms of the economic aspects of the models were answered by our combined LP/IO model, which you did not discuss in your review, although it is fully developed and being used.

The size limitations you give on ESNS and BESOM are not inherent. The ESNS user may specify additional supply and end-use processes up to a much higher total than your statement implies, and this is being done at present. BESOM now contains 27 supply categories and 22 demand categories. This is not due to size restrictions, and we are free to add more categories when we feel they are needed. Finally, it is misleading to compare numbers of ESNS supply links with numbers of BESOM supply categories, since links

and categories are quite different entities. ESNS does have a more highly disaggregated set of end-use demands, but end-use links and demand categories are not strictly comparable.

It is true that ESNS is not coupled with any economic models, but BESOM incorporates supply curves and demand elasticities as a fully operational optional feature. Moreover, BESOM is coupled with an input-output model. The combined model is completely developed and is being used, and alleviates many of the economy-energy sector problems you mention. This model linkage allows for energy demand projections via conventional IO final demand projections. In addition, we have just started to interface the combined LP-IO model with Dale Jorgenson's (Data Resources Inc.) inter-industry and macrogrowth model. This interface will permit better treatment of price, tax, and other policy related data.

Ellen A. Cherniavsky
Brookhaven National Laboratory

The discussion on the level of aggregation of the supply and demand sectors should include a more thorough description of the EMDB. The Energy Model Data Base 'presently contains two files, one dealing with processes associated with current energy technology supply modes -- extraction of coal by strip-mining catalytic cracking of petroleum, pipeline transport of natural gas, etc. -- and one dealing with the present utilization of energy for various purposes in the residential, commercial, industrial and transportation sectors -- residential space heating by natural gas, steel production by electric furnaces, air passenger transport by jet fuel, etc.'" The supply file presently contains 600 processes and the utilization file contains 200 processes. In short, the EMDB is sufficiently disaggregated in both supply and demand categories to handle almost any type of analysis. Furthermore, it is flexible enough to include additional processes or categories as needed. Thus it would be relatively easy to separate high and low sulfur coal. However, since the EMDB does make regional distinctions in the supply file and since coal characteristics are largely determined by the region in which the coal is situated, the capacity to discriminate between high and low sulfur coal already exists. At present, as you point out, the Basic and Modified Models must aggregate the data from the EMDB because of size restrictions on ESNS and BESOM. However, as experience with the models is gained and a need is demonstrated for more disaggregated analysis, we see no reason why ESNS and BESOM cannot be expanded. The BESOM linear programming model is relatively small, as far as linear programming is concerned, and considerable expansion of this model would cause no difficulties in terms of computing a solution.

Basically, we agree with your comments on the economic aspects of the model. We do think however that the coupling of the I/O Model with BESOM is significant enough to warrant more enthusiasm. This marriage may overcome the major disadvantages of both Models, as you point out. Furthermore since the level of technological detail is comparable in both Models, the coupling process is straightforward and direct. We also don't see the problem in using a "staircase" supply curve in the optimization in order to determine the societal demand since with long term fuel contracts and high costs of capital, it is doubtful that fuel substitution in the real world conforms any better to the traditional economic view, particularly in the short term. One should be careful to recognize that the demand arrived at through shadow pricing techniques is not the usual economic demand. In the Model the supply curves are exogenous and the demand is associated with the shadow price generated for a given constrained quantity of fuel. The equilibrium point is determined by minimizing the societal cost, or some other function, while total energy demand is held constant. Thus interfuel competition is stimulated but competition between energy and other goods is not. The authors of the Model imply that this minimization yields a social optimum. However, one must be careful in equating the shadow price with social value. For example, the shadow price of natural gas may be unduly high if it is competitive, while the fuel it replaces (e.g., petroleum) is noncompetitive, and therefore inflated in price. The shadow price for natural gas in this case will not be a true measure of social value as it will include the monopoly profits of the petroleum industry. The optimal solution in this case will show greater use of natural gas than the true social optimum. In another example, we can see how the shadow price may be too low. Suppose we are considering the replacement of coal with natural gas while we are minimizing only total cost. In this case, the shadow price for natural gas will be too low as it does not reflect the social value of less pollution. This of course could be dealt with by placing a dollar value on pollution.

Throughout the review, the limitations of the BNL Models are constantly underscored due to their use of national data. We feel that, as a criticism, this has been overemphasized. There are many problems where national data is meaningful (e.g., assessing the effect of a perturbation on acid rain phenomena; also see discussion on page 24 of ref 3). In any case, developing and using a sound national model can serve as a learning experience and help to focus clearly on the relevant interregional aspects which must be included in a more general model. An interregional Modified Model,

BNL is currently investigating some very attractive refinements of BESOM. These include two dynamic versions of the linear programming model. In one of these, the optimization is performed for each year over a prespecified time horizon, with the optimal solution for one year providing the input for the ensuing year. In the second model, a "global" optimization over the entire time horizon is conducted; the latter model is considerably larger than the former. At this point however, we cannot judge how effective these refinements will be.

Summary

The BNL Models are mature in that they have been around, in some form, for a few years and have been used in a variety of studies. Furthermore, the detailed components of the Models (i.e., EMDB, EMIP, etc.) presently exist, are well documented and operational. The Basic BNL Model as you say is "an excellent accounting tool for compiling, storing and displaying total costs and impacts for prescribed energy supply mixes" on the national and regional level. However, it does not interface at all with economic considerations and has no predictive capability. The Modified BNL Model with the inclusion of supply elasticities appears to be an excellent tool to describe fuel and technology substitutions. Its coupling with I/O holds great promise for simulating competition between fuels and other goods, given a set of supply functions. However, the detail of the Model, which uniquely qualifies it to deal with some very specific problems in technology assessment, becomes rather unwieldy if we try to build it into a complete predictive model like that of Hudson and Jorgenson, which by necessity is far more aggregated. The prospect of simulating demand behavior in the complete detail the Modified Model requires, and then simultaneously determining the supply and demand appears to be a monumental if not impossible task.

Southern Illinois University

Energy Management Simulation and Analysis System (EMSAS)

Enclosed are some very minor comments relative to the material you sent me. I have no general comments with respect to the critique, although I do think that the description with respect to comprehensiveness fails to describe the considerable detail which we've built up on terms of supply forecasting (i.e., drilling and exploration). Finally, there seems to be no discussion of fuel substitutability modeling which is modeled in considerable detail.

Donald F. Blumberg, President
Decision Sciences Corporation

Hudson-Jorgenson Energy Model

My comments on your review of the Hudson-Jorgenson energy model are as follows:

1. Section 3.5.3: The reason our estimates of energy use from 1975-2000 are lower than such competing estimates as Dupree-West and the National Petroleum Council is that we take into account the drastic change in energy prices that occurred in 1973-74, while they do not. Although it is obvious how such changes can be incorporated into our model, I would be at a loss to attempt to modify the Dupree-West or NPC projections to incorporate price changes. This point is made in a more general way by Hudson and myself on comparing our approach with the energy balance approach in our Bell Journal paper.

Your point about conservation and environmental policies is certainly well taken. To incorporate such policies, their effects would have to be translated into effects on prices. So far as changes in technology are concerned, we are currently collaborating with Brookhaven to integrate their Energy Reference System with our model in order to deal with new technologies. The resulting model will effectively substitute the Brookhaven representation of energy-energy transformations for our present representation. You are certainly correct in pointing out the limitations of our present analysis of potential technical change.

2. At a number of points you state that our assumptions about supply are unclear. Our supply assumptions are based on constant returns to scale in each industry. For a given set of prices, the supply curve for industry is horizontal. By comparing our estimates of supply price with estimates available from other sources, we can calibrate the model to a particular set of supply assumptions. We have formalized this procedure for the supply of petroleum and natural gas.

3. The cost of energy affects economic growth by increasing or decreasing the overall efficiency of the economy. In order to calculate impacts of changes in energy prices on GNP and the general price level, we estimate GNP by summing over the outputs of the individual industries. We then feed this back into the macro-model. For practical purposes this process converges in one step, so that we have not formalized the simultaneous solution of the macro-growth model and the inter-industry model. We are now undertaking a project to do so.

I very much appreciated the opportunity to study your review.

Dale W. Jorgenson
Department of Economics
Harvard University

Kalter's Parametric Models of Fossil Fuel Markets

This is in reply to your... critique of my Department of the Interior study. I read your comments with interest and have no disagreements with your conclusions. It appears that you have caught the essence of the approach and its major advantages (disadvantages).

Robert J. Kalter, Assoc. Professor
of Resource Economics
New York State College of
Agriculture and Life Sciences
Cornell University

Project Independence Evaluation System

Your critique of the PIES model is lucid and, for the most part, accurate. I have the following specific comments:

1. Page 77 -- last paragraph. The scenarios chosen were not intended to exercise the model as your wording implies. The model was simply one tool used in the analysis. Although the report was not intended to recommend specific policies, it was clearly intended to stake out the boundaries of the effects of broad policy alternatives.
2. Page 84 -- end of first paragraph. Since base load plants operate at higher capacity factors than other categories, the percentage of base load capacity of total capacity is much less than 75%. Furthermore, we do not exogeneously specify proportions of new and old plants. It is possible for only new plants to be peaking plants.
3. Page 88 -- first paragraph. The reference to quadratic programming is irrelevant. The quadratic formulation attempts to deal with the problem of cross-elasticities by assuming linear demand functions. We circumvent this problem by using discrete approximations of the demand functions, but adjusting our approximations to take into account cross-elasticities on successive iterations.

Michael H. Wagner
Chief, Energy Process Modeling
and Integration Division
Federal Energy Administration

Wisconsin Energy Model

In general, we agree with your assessment of the limitations and potentials of our model. However, we feel that we rely less on trends than you indicate. Supply and

demand models are based on physical and engineering principles for the production, transmission, and consumption of the various forms of energy. The parameters of the model are demographic and technological factors (e.g. family size, miles per gallon, and dollars per installed kilowatt capacity). As such, the model parameters may readily be changed by the user to examine the impact of policy changes in the future.

The subroutines that comprise the WISE energy model are written in a general enough form to apply to other regions. The basic assumption behind the transference of the models to another location is that the physical and engineering mechanisms remain the same. The user must specify the local demographic and technological parameter values, but the model structure remains the same.

The model does not predict the future, nor constrain the future trends to be like the past. Rather, the model allows the user to specify his expectation for future changes in both policy and technology, and to examine the resulting energy scenario. The model has proven to be a powerful tool for analyzing a variety of policy and technological issues arising in the state including, the future demand for electrical generating capacity, the impact of the Commercial and Public Building Code, alternatives for energy conservation, and the impact of a natural gas diversion.

John W. Mitchell
Acting Director
Energy Systems and Policy Research Group
Institute for Environmental Studies
University of Wisconsin - Madison

APPENDIX B. The Energy Input-Output Matrix

The Energy Input-Output (I/O) Matrix for the United States is an application of the economic I/O model of economic system interaction developed by Wassily W. Leontief.¹ This energy utilization model was developed by Robert A. Herendeen at the Oak Ridge National Laboratory as a staff member of the ORNL-NSF Environmental Program² and has been continued at the Center for Advanced Computation at the University of Illinois.^{3,4}

The economic input-output model uses the dollar value of flows of inputs and outputs (purchases and sales) among the economic sectors of a complex industrial society as a measure of the flows of raw materials, intermediate products and final products. In the process the model identifies the level of input from each sector of the economy to every other sector. By transformation to I/O coefficients, the I/O matrix or table gives a comprehensive structural description of the economy for the data year. The I/O coefficients form a system of linear equations connecting the inputs and outputs of all sectors.⁵

The energy I/O transforms the dollar flows to energy flows and creates the ability to determine the embodied energy that goes as inputs into the process of manufacturing, transporting and sale of final products used in the economy as well as energy used as a final product. "This is very important, since typically the total energy far exceeds that used in the last step. For example, ... the auto industry itself uses only about 7% of energy needed to make a car."⁶

The objective of the model is to analyze the current energy relationships and technological processes in the economy as well as the constraints in the system due to limitation of energy availability. In concert with related auxiliary I/O transformations, such as man-years per dollar of output of each sector by job category and special purpose data such as pollution emissions, the I/O model enables one to estimate the impact of public and private policy alternatives or scenarios of alternative energy availabilities or efficiencies in energy use.⁷

The model is built in three stages. The first is a geographic area input/output matrix for all sectors in dollar terms. The matrix is empirically derived from Census of Business data collected by the U.S. Department of

Commerce plus related data from other sources. The second stage is a transformation of the first table to technical coefficients that represent the inputs to each industry and value added by that industry divided by its output. This stage enables one to determine the effect of changes in levels of activity in a sector on the remainder of the system.

The third stage is a transformation of the energy sectors of the economy from coefficients in dollar terms to energy terms in British thermal units (Btu). Here the I/O table shows the output of each energy sector required for the sale of a dollar's worth of final product of other sectors.

In addition, the model can be tied to external information for analysis of policy alternatives, energy availability scenarios, and optimization of stated goals as discussed briefly above.

In its treatment of energy sources and demand sectors, the model is comprehensive, and in this respect it is limited only by the detail of data available for the transactions among sectors in the economy. The 1958 U.S. Table prepared by the Department of Commerce contained 87 producing sectors.⁸ The 1963 U.S. Table contained 367 sectors,⁹ as did the 1967 U.S. Table.¹⁰

Herendeen uses five energy sectors: coal, crude oil and gas, refined petroleum, electricity, and gas.¹¹ The limitation here is practical. Finer energy sector breakdowns are possible with better energy data collection, which can be expected in the future. For example, the Bureau of Economic Analysis (BEA) has recently broken down the petroleum sector to disaggregate jet fuel, gasoline, distillate fuel oil, residual fuel oil, and other petroleum products.¹²

Sectors in the BEA 1963 Input/Output Table, the basis for Herendeen's energy I/O table, are based on the establishment and are "built on economists' definitions" and Herendeen points to the difficulties in transforming their dollar matrix to physical (energy) terms.¹³ The data on energy supplied to industry is satisfactorily documented and conversion to I/O format from Census of Manufacture data is accomplished by Herendeen. However, energy data for about 60 sectors, including transportation, agriculture, construction and service industries, are not easily documented; therefore, he has made the transformation using a variety of sources of energy utilization data.¹⁴ The table for 1963 has been reworked using refinement of data and techniques, and

published with a table of 1967 data. The tables list input from five energy types (coal, crude and gas wells, refined petroleum, electric utilities, and gas utilities) and total primary energy to 357 sectors. Energy intensities for the nonenergy sectors are in Btu per dollar. For the energy sectors, intensities are in Btu per Btu of output.¹⁵

Though the model is a national one, the methodology can be used for any geographic configuration for which data can be obtained or constructed. This capacity of the model is important for regional studies whether they be for national regions, metropolitan regions, or irregularly shaped natural resource (supply) regions. The availability of data for regional configurations, however, is a problem that must be acknowledged. Regional studies must often use a smaller number of sectors because of limited data availability and disclosure problems.

Analysis of energy sectors in terms of the flow of fuels through the extraction, processing, transportation, and end-use stages appears to be at least partially a problem of definition of sectors in a manner that can deal with the flow. Herendeen has dealt with the problem in an ad hoc manner based on availability of data and methodologies that he determined to be usable.¹⁶ Current work in progress should aid in solving this problem.¹⁷

The energy input/output model represents an empirical accounting of the flow of activity in an economic system. Since this flow is affected by prices, labor, value added, material availability, and governmental spending, the model can be adapted to examine a variety of problems and is therefore an inherently flexible framework for analysis. Leontief, for example, has shown how an input/output approach can analyze environmental pollution relative to external costs and thus these costs can be included in costs of production.¹⁸ Isard has used the input/output approach in analyzing the effect of a new commercial activity on an ecosystem in the New England area.¹⁹ The increasing development of data and coefficients by researchers and governmental agencies for their particular purposes, in a manner compatible with input/output analysis, increases the range of possible use of the methodology. Clearly the expansion of uses of the input/output approach is growing. The effectiveness of I/O data has been somewhat diminished by the length of time required to prepare national I/O tables (about seven years after data collection). This is changing. The BEA is expected to update an 83-sector table annually.²⁰

The model as developed by Herendeen is a national model and does not attempt to deal with interregional relationships. There is no methodological barrier in achieving this capability. The application of the multiregional input/output analysis developed by Leontief and Strout appears appropriate.²¹ Carter has discussed the need to use a multiregional I/O approach to analyze the problem of allocation of scarce fuel resources.²²

Intraregional energy market relationships are represented by the technical coefficients. The validity of the coefficients for long range forecasting is related to the general problem of modifying the coefficients to reflect changing technology and price relationships. If the region is quite large and the market is considered to be too diverse for the purposes of the analysis, it can be viewed as a system of smaller regions. Such a system can be composed of states, or standard metropolitan statistical areas and non-urban regions, similar to the BEA division of the U.S. into 1973 economic areas that contain 253 SMSAs and 173 non-SMSA portions.²³

The energy input/output model determines final product for energy in the energy and nonenergy sectors. Demand must be determined exogenously. The I/O methodology is generally used for determining the inputs to exogenously determined levels of final consumption through the use of "closed" I/O systems.²⁴ This analytical capability allows the use of consumer coefficients that are capable of considerable change based on various assumed consumer patterns. The analyst is thus enabled to program consumption patterns as part of policy analysis and to determine the effects of limitations in final goods availability (such as low mileage automobiles) on the energy flow throughout the economic system.

Price and substitution relationships have not been dealt with by Herendeen thus far. Such relationships require linkage to econometric models. This aspect of energy utilization analysis is not a simple one, particularly for industrial sectors. Substitution is related (among other things) to investment in capital goods that are not readily replaced as energy price relationship changes. Carter has dealt with the problem at length in Structural Changes in the American Economy.²⁵ Substitution effects and diffusion of technological change are not distinguishable empirically.

Herendeen states that "The implied intent of this work is usefulness in projecting." He readily acknowledges that there are problems in use of the methodology. Time variation of coefficients is affected by inflation, and when the rates differ among the sectors the usability of the coefficients is affected.²⁶

The usability of the I/O model is also affected by the changes in technical coefficients that represent the entire fabric of interrelationships in the economy. The introduction of new technologies by the system is not uniform but the matrix assumes no change in the coefficients' relationship. Carter has shown that technological change moves slowly through the economy and thus the technical coefficients are relatively stable.²⁷ A change in one area may be rapid but not create much change in the matrix. If one is interested in the whole economy it will not be important; however, if one is interested in a sector or function (in this case energy) and if there is a rapid shift in technology, the coefficients will have to be modified to reflect this situation. The estimate of the pace of technological change is speculative. For example, claims for the potentiality of oil from shale have been strongly modified in recent months as costs have increased rapidly and process water availability and environmental problems of extraction and processing have been faced more soberly. This problem of technological change is a significant limitation in use of I/O methodology for long-range, energy supply-demand analysis.

The problem of supply of fuel is a battleground between those who see it as a geologic question and those who believe that substitution relationships require only that prices be high enough to induce production of less economic sources (compared to the past) or substitution of less energy-intensive technology. This problem has been recently addressed in a study for the National Academy of Sciences.²⁸ Limitations of resource availability lends itself to I/O analysis for allocation by utilizing linear programming for optimization of determined policy goals.

A problem that has not been faced satisfactorily is that of the assumption of proportionality in I/O relationships. The relationship of the coefficients in the table requires the assumption that a 10% increase in output in sector A (for example) will require a 10% increase in input from each sector related to the output of sector A. This proportioning ignores the

entire problem of economies of scale. In addition, the new concern for energy costs and availability has brought about a widespread review of industrial and other economic activities with the view in mind of reducing waste. This in effect increases efficiency in energy use and lowers the energy coefficient for a sector, but it is difficult to adjust coefficients for this effort in the short run.²⁹

The problem of evaluation of policy options is a difficult one for society. This is particularly true for energy since it rose in our national consciousness so rapidly. The input/output model is a useful tool in evaluating the effects of policy options. The I/O model has a minimum of assumptions that will force results. It has great flexibility in dealing with policy questions for various sized and shaped geographic aggregations and can deal with inter-regional analysis.

The model has limited utility by itself for long-range forecasting. Since the model has static relationships, it must be linked to other models to increase its usability. Coefficients derived at a previous time may be less accurate than desirable for present use. Construction of future coefficients for analysis of future energy scenarios is hampered by value judgments. The model is vulnerable to problems of data availability. Since it is an empirical model, it is only as strong as the accuracy and usability (timeliness) of the data.

Data is becoming available in a more timely fashion as a variety of researchers and agencies have increased their use of I/O methodology. Although the model has serious limitations by itself, it can serve a valuable function as input to more comprehensive systems.

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APPENDIX C

Testimony before the Joint Economic Committee on
THE FEA'S PROJECT INDEPENDENCE REPORT

by

M. A. Adelman, Professor of Economics, M.I.T.
Jerry A. Hausman, Assistant Professor of Economics, M.I.T.
Henry D. Jacoby, Professor of Management, M.I.T.
Paul W. MacAvoy, Henry R. Luce Professor of Public Policy, M.I.T.

March 18, 1975

The Project Independence studies carried out by the FEA (Federal Energy Administration) during the past year are an important step in the nation's attempt to understand our emerging energy problems and to formulate policies to deal with them. We are happy to have the opportunity to participate in this discussion of the work, and its strengths and weaknesses.¹ The object of our comments is the Project Independence Evaluation System (PIES), which is the overall analytical apparatus developed by the FEA to support their studies.

The system consists of three groups of interrelated models and associated data. The centerpiece of the system is a large linear programming model which is used to estimate domestic energy consumption, production, prices, and imports for different regions of the country. This integrating model uses as input estimates from models of domestic demand and production of oil and gas. Other important inputs include price-sensitive estimates of coal production, estimates of the availability of other fuels (solar, geothermal, hydropower, nuclear), information on transportation costs between regions, and estimates of the associated requirements for equipment, labor, capital, and water. Sub-models of the electric utility and refining sectors are included in the integrating model itself.

¹This testimony reflects the preliminary results of a review and evaluation of the Project Independence Report carried out by the Policy Study Group of the M.I.T. Energy Laboratory under contract to the National Science Foundation, Office of Energy R&D Policy. These comments also draw on other work by the Group over the past 15 months, which has been supported in part by grants from the Rockefeller Brothers Fund and several private donors.

Once the integrating model has been solved for a given year, the results may be further analyzed to obtain information on macroeconomic and environmental effects, and on resource and financing requirements for the calculated energy production schedule.

The FEA uses the PIES apparatus to evaluate three broad policy strategies that the U.S. might adopt for the next ten years:

1. A "Business as Usual" strategy, which assumes the removal of oil price controls in 1975, and phased deregulation of natural gas prices.
2. An Accelerated Development strategy, involving removal of obstacles to the development of offshore oil and gas, synthetic fuels, and nuclear power.
3. A Conservation Strategy, involving specific conservation initiatives -- such as 20 mile-per-gallon auto standards and improved heating and lighting standards for new homes -- and "demand management" measures that entail increasing electricity usage, with supply from coal-fired electric power.

Each of the scenarios is analyzed for the years 1977, 1980, and 1985. The basic external condition that influences the analysis is, of course, the price of world oil. The FEA study assumes that the world price will converge on some value in the near future, the precise level of that price being unknown. The comparisons are done under the assumption of world prices of \$7.00 and \$11.00 (in 1973 prices) delivered to U.S. shores.

The key results of the overall analysis are: If the world price settles at \$11.00 in 1973 prices (which is roughly \$13.00 to \$14.00 per barrel in today's prices), then by 1985 under "Business as Usual" we will be importing 3.3 million barrels per day (about half of today's level). If the world price drops to \$7.00 per barrel in 1973 prices (or roughly \$8.00 to \$9.00 in 1975 prices), then by 1985 our imports will be up to 12.3 million barrels per day. With conservation or accelerated development measures, these imports can be reduced by various amounts.

Overview of the FEA Study

Now since our testimony here is a critical review and evaluation, it does by its very nature tend to focus on specific points of weaknesses in the material being reviewed. It is well to start, therefore, by putting this work

in context and commenting on the overall effort as a whole. Several points are worth mentioning. First, at the time the study began there was no coherent data base for analysis of the many facets of the U.S. energy sector, its relation to the economy, and the federal and state policies that influence energy supply and utilization. Scattered data series existed, many collected by federal agencies, but for coordinated analysis such as that mandated for the Project Independence study, a massive effort of data collection and processing was required. No doubt PIES is only a step in the process of creating a data base adequate for federal analysis and monitoring of national policy; but it is a critical step.

Moreover, a set of analytical models has been formulated for utilizing these data to forecast future energy conditions. Heretofore there were scattered modeling efforts, both in and out of the government (indeed, given the time constraints, much of PIES had to be a patchwork of analytical models and associated data drawn from other sources), but nowhere within the government had it all been put together into a coordinated framework for analysis. Thus, although there are differences of opinion about the overall design of the PIES system (and below we level strong criticism at specific parts of its current structure), the fact remains that the various pieces have been brought into a coherent system. The PIES can provide a framework for managing data, coordinating judgments, and forcing consistency in the various assumptions required to formulate and assess national energy policy.

Having said that, we must look at the work as it stands and evaluate it from three points of view:

1. Did the FEA study illuminate the most important questions, and did it adopt the proper set of assumptions and conditions to be analyzed?
2. Was the analytical apparatus adequate to the task?
3. Are the correct implications drawn from the analysis?

As you might anticipate, the reviews are mixed, and there is no clear answer to the effect "yes, they did it right," or "no, they did it wrong." But an attempt to answer these questions gives us a feel for how wide a band of error should be put around the FEA estimates, in what directions the possible bias may lie, and where more work must be done in order to do better in the future. Our list of the most important points to worry about is the following.

The Oil and Gas Supply Estimates

The supply estimates for domestic oil and natural gas are based on a modified version of a model developed originally by the National Petroleum Council. Under this procedure, oil and gas supply are calculated by assuming the amount of drilling that is profitable in each of 12 regions in each year, multiplying this by stipulated rates of reserves-added per foot drilled to get total reserves, and then assuming that reserves are produced at a certain rate. At higher oil or gas prices more drilling becomes profitable, and production rises. It is a method that is almost totally dependent on the judgment of the analyst feeding-in drilling and discovery rates to the computer program.

There are systematic problems with this analysis. The method has been applied in a way that appears to underestimate the likely response of oil and natural gas supply to price changes. This occurs because, under the FEA procedure, an increase in price in 1975 brings about increased drilling only after 1980 or even later. This belies the activity we see taking place in the domestic petroleum industry today. In particular, the method seriously underestimates the likely level of exploratory activity for natural gas by basing the expected drilling rates on the experience of the early 1970s, when gas drilling was dampened by the effects of field-price regulation.

Taking these considerations into account, one can argue in the case of oil that the responsiveness of investment to price is underestimated in the model. On the other hand, it is not clear whether adequate weight was given to certain opposing influences -- in particular, the declining responsiveness of supply to investment because discovery will continue its decline, and because improved recovery out of a given amount of oil in place will come at sharply higher real costs. On balance, then, there is little solid ground for arguing that the estimates are high or low overall. An M.I.T. model forecasts supplies very similar to the FEA results at \$7.00, and other estimates are scattered above and below it. But the uncertainty is great, and we would not use the FEA forecasts for policy analysis without considering that the estimates of, say, 11.9 million barrels per day in 1985 at \$7.00 per barrel can easily be off by 1.5 million barrels either way. In natural gas, on the other hand, the FEA analysis seems unduly pessimistic. Here the error band is also wide, but would extend from somewhere in the neighborhood of the FEA estimate [11.9 million barrels per day (oil equivalent) in 1985 at \$7.00 per barrel] to two or three million barrels per day above this level.

Perhaps as important as the potential errors and biases in the FEA estimating method is the fact that the most important issue of the day, the effects of price controls on the supply of these fuels, was not satisfactorily analyzed. We have argued that the analysis tends to understate the importance of higher prices even in the \$7.00 to \$11.00 range. We also believe that continued price controls on oil and field-price regulations of natural gas would have a significant dampening effect on the domestic supplies of these fuels. Unfortunately, the fact that the study contains practically no analysis at all of the potential significance of price controls, coupled with supply estimates that show very little response to price, gives the erroneous impression that price deregulation is not an important issue influencing future U.S. energy sufficiency. We do not believe the FEA intends to convey this impression, but it is there nonetheless, given the structure of the analysis, the particular assumptions made, and the scenarios chosen for detailed analysis.

The Electric Power Sector

One of the very good features of the PIES integrating model is the way it handles the electric power sector. The analysis is sound, given its assumptions. Unfortunately, the assumptions tested in the FEA analysis fail to illuminate the most critical problem of this sector and one of the key determinants of its future growth, i.e., the financial health of the investor-owned utilities. It is now apparent that without substantial rate increases allowed by the state regulatory commissions, it is unlikely they will be able to raise sufficient capital to expand their systems to the levels implied in FEA analysis, or with the technology mix assumed [i.e., heavy investments in capital-intensive coal and nuclear units]. These financial difficulties, if they continue, will lead to reduced levels of system reliability and reduce the desirability of electricity to consumers. This will curtail demands for this form of energy (and thus call into question the "demand management" strategy presented in the Project Independence Report), but may also raise demands for other fuels, most notably imported oil.

Of course, the FEA report discusses this problem; but it does not analyze its quantitative significance. The lack of analysis of this issue -- its implications, and what it might be worth to avoid its occurring -- is an important shortcoming in the FEA's study as it stands.

The Demand Analysis and Its Interaction Within the Integrating Model

In estimating the future demands for energy in the U.S., the FEA used a three-step form of analysis whereby (1) aggregate national energy demand was estimated given a forecast of the average energy price, (2) this overall Btu demand was split up among fuels using a separate estimating model, and (3) national demands for specific fuels were divided among regions according to their historical proportions.

When applied to the data for U.S. energy -- clouded as it is with regulatory interventions and rapid growth in the network of natural gas pipelines -- this procedure did not yield results that were consistent with what one would expect to be the behavior of this sector under alternative prices. For example, the analysis showed natural gas demand falling in certain use sectors when prices of distillate oil rose. Since these two fuels are close substitutes for one another, one would expect the opposite result. Attempts were made to correct the deficiency (and this effort continues at the present time), but even given these efforts, the interaction of the flawed demand model with the integrating framework leads to an identifiable bias in the results.

In essence, the problem is that, since natural gas demand is assumed not to rise as oil prices rise, then the price of natural gas is never driven to levels that are consistent with the high price of the substitute fuels. In effect, the price of natural gas stays at a level appropriate to a world with \$7.00 oil even when the price of oil from the world market (which determines the domestic price) is assumed to be \$11.00. This means, in turn, that the price of an average Btu in 1985 with \$11.00 oil is understated, and the overall demand is thus overestimated. When these problems are corrected, we expect the FEA will find that oil demand as estimated in the November report is biased upward, both due to the upward bias in overall energy demand, and due to the inaccurate representation of how much of this total demand will show up as a demand for natural gas.

Another problem that tends to an underestimate of the dampening effect of higher oil prices is the fact that the FEA was unable to take account of the fact that overall GNP growth will be affected in some measure by higher oil prices. No doubt, this is not a phenomenon that anyone has modeled very satisfactorily, but the fact that it does exist should be kept in mind when applying the appropriate error range around the FEA's forecast.

The International Assessment

It appears that the FEA devoted the great bulk of its resources to the domestic aspects of the energy problem, and applied only a small fraction to the international phenomena that are the immediate cause of current difficulties, and the driving force behind their evolution. The FEA analysis is based on a set of judgmental estimates of oil demand in the world and oil supply from non-OPEC countries, which yields a residual demand for the exports of the cartels. This net demand is then compared with the potential supply from cartel nations (which is very great, and at a cost far below current prices) in order to get an idea of how big a problem the cartel may have in avoiding a flooding of the market with oil, and consequent erosion of price. The analysis assumes that the world price will gravitate to one level or another; it may stay near \$11.00 per barrel (in 1973 prices), or more likely it will settle to a price around \$7.00 a barrel. These long-term price scenarios then provide the link between the international assessment and the domestic evaluation discussed above.

Unfortunately, this vision of a smooth evolution of prices to some stable value is a serious oversimplification of reality. In fact, there are forces at work in this market that make it more likely for the price to fluctuate over time. For example, as prices rise there are factors that tend to reduce supply and drive prices still higher. Oil-rich exporters find their revenue needs are easy to satisfy under rising prices, and they can more easily afford to cut production. Outside the cartel, in those nations where oil exploitation is in private hands, rising prices present serious equity problems due to the excess profits that accrue to private corporations. Governments of these countries are led to impose tax schemes that have the side effect of reducing the incentive to expand oil supply. (Our own struggle in the U.S. with this issue is all too evident; the problem is duplicated in Canada, in the nations surrounding the North Sea oilfields, and elsewhere.) To the extent that these phenomena lead to reduced supply, it becomes easier to maintain high prices or to further increase them.

On the other hand, it is likely that prices eventually will turn down from current levels, for in time high prices lead to reduced demand, to gradually increasing supplies from outside the oil cartel, and thus to a sagging demand from the cartel members. Once price begins to erode -- perhaps due to

a buildup of excess capacity and an attempt by some cartel members to compete for a larger share of the depressed market -- forces are set in motion that tend to drive the price down further. Oil-rich countries will have built up domestic spending programs and high imports under high prices, and if prices fall these governments will be under strong pressure to increase oil production to pay the bills. Further price shading will be required to move larger quantities of oil, and so the process feeds on itself. Naturally, if the cartel should break, and prices fall considerably, immediate efforts would be made to reconstitute the cartel and raise prices again. There is no inherent reason why, over a short-run period, they should not once again be successful.

If in fact it proves true, as we believe it will, that this market and the cartel structure that dominates it are likely to prove unstable, then the world oil price could, over the period to 1985, fluctuate over a range significantly wider than the \$7.00 to \$11.00 range used by the FEA as a basic assumption of their work, and at the very least the price is unlikely to gravitate to a level which is in fact stable, and which people believe is stable.

In these circumstances there is no reason to expect that a reduction or increase in import demand by any one country will have any effect on the world price. This is a persistent notion: One of the major conclusions in the Executive Summary of the PIR is that our actions to achieve self-sufficiency could have an appreciable effect in bringing the world price down to \$7.00 per barrel. But there is no analysis in the FEA report to support this assertion, and we believe it is mistaken.

Summary and Conclusions

Considering the state of the data and available models when work began and the short time available, the FEA's Project Independence study is an impressive accomplishment. It seems clear that the government needs the in-house capability to do this kind of analysis, and that these efforts should be continued and improved.

In viewing the results of the work as of today, however, several points are worth keeping in mind.

1. There is considerable uncertainty in the estimates of domestic supply and demand; net imports, being the residual, is subject to even greater uncertainty. However, given the assumptions behind the analysis, the FEA estimates of U.S. import dependence in 1985 appear to be biased upward. At \$11.00 per barrel oil prices, the U.S. is more likely to be self-sufficient in energy than the FEA indicates; at lower oil prices, imports are likely to be smaller than forecast by the current PIES apparatus.
2. Due to various shortcomings and difficulties in the PIES analysis, it appears that the likely responsiveness of the U.S. energy sector to price increases has been underestimated. Problems in the demand analysis, when corrected, are likely to show a stronger adjustment to price change, and the particular method used to estimate oil and natural gas supply tends to underestimate the effect of price on domestic fuel supply.
3. The likely underestimate of supply responsiveness, coupled with the fact that the analysis does not deal with the effects of price controls on demand and supply, means that the Report as it now stands gives an inadequate appreciation of the stakes that are involved in current policy discussions about price control or decontrol.
4. In the set of PIES results presented in the Project Independence Report, it is assumed that there are no problems of capital availability that impede desired investments in the energy sector. There are several points where this assumption might be questioned (and where, indeed, the FEA study worries about it), but nowhere is it more limiting than in the case of the electric power sector, where some of our gravest energy problems arise. The study does not indicate the degree to which a faltering of investment in electric power may reduce the use of domestic coal and nuclear energy and increase dependence on foreign oil.
5. The report focuses on policies to deal with an external world where there may be a threat of short-term market disruption (for example, through boycott) and a foreign exchange drain if prices are high, but where the price is reasonably stable and where investors and consumers have a stable expectation of what it will be in the future. This means the report as it stands does not provide the analysis to aid decisions on policy issues -- such as tariffs, import quotas, subsidies and guarantees for synthetic fuels, etc. -- that are required in a world of fluctuating uncertain oil prices.

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