ENERGY DEMAND IN THE ERDA NATIONAL R,D&D PLAN

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1. Introduction and Summary

The purpose of this paper is to review the demand scenarios used by ERDA in developing the national energy R,D&D plan. The paper is organized as follows: in Section 2 we review and evaluate the analytical apparatus used by ERDA in analyzing the scenarios presented in the plan. We then describe how ERDA utilized this analytical apparatus. In Section 3 we evaluate ERDA's procedure both from a logical point of view and by comparing the ERDA results with other similar forecasts.

The results of our review may be summarized as follows:

1) ERDA's forecast[1/] of both primary energy supplies (coal, oil, gas and uranium) and final end use demands are independent of future energy prices. This is a consequence of a decision not to directly incorporate into the analysis assumptions about the future world price of oil, and the fact that the analytical models used to support the analysis cannot presently accommodate a price sensitive energy demand model.

2) Comparing the ERDA baseline forecase with the FEA Project Independence Report forecasts for 1985 indicates an implicit assumption of approximately $9.00 per barrel (1973 constant dollars). At this price the ERDA forecast of imports of petroleum seems too high. As a consequence, the estimates of the impact of the R, D&D program in contributing to the energy independence seem to be over estimated.

3) The relationship between the energy demand forecast and the demand by the household and industrial sectors for other factors of production such as capital, labor, and other materials is not explicit in the ERDA analysis, nor in the analytical models used by ERDA to support that analysis. Various passages in the report indicate ERDA's belief that energy markets and other

factor markets are intimately related, so that substantial changes in energy supply and demand serious affect other elements of the economy and aggregate economic growth. This belief is not reflected in the analysis.

4) The analysis of the conservation scenario is inadequate in that no information is provided concerning policies and program initiatives which would cause the changes in conversion and utilization device efficiencies assumed by ERDA. As a consequence, the cost of implementing conversion initiatives cannot be contrasted with the cost of supply initiatives. In our view this is the most serious shortcoming of the analysis.

5) No information is provided on the expected regional implications of the plan.

6) In summary, we find that ERA has employed a consistent framework and set of assumptions in developing and analyzing alternative scenarios. The assumptions employed concerning the demand for and supply of primary energy inputs seems too restrictive to us, leading to potential biases in the results. However, the methodological approach which ERDA has chosen can be modified to incorporate a more complete model of the energy system which will provide ERDA with an apparatus which is potentially both more accurate in its forecasts, and richer in its economic interpretation.

We recommend the following research and analysis activities to be undertaken to support the preparation and presentation of the next Plan:

1) Integrate into the ERDA analytical framework a suitable end use demand model and supply models for primary energy inputs. These models should have a regional dimension.

2) Move in the direction of relating energy markets to other factor demand markets and to a macroeconometric model of the U.S. economy. Develop a more suitable macroeconomic framework to support development

and analysis of the Plan.

3) Undertake an intensive modeling effort to reflect potential conservation initiatives in both conversion and end use technologies so that these technologies can be consistently compared with supply technologies in terms of contribution to reducing overall energy costs.

4) Increase the level of effort devoted to documentation and publication of basic technological and resource data used in analyzing the plan.

2. ERDA Methodology

In developing a national energy R, D, & D plan, ERDA constructs and analyzes six scenarios of the domestic energy system for the years 1985 and 2000. The scenarios are:

(1) Scenario 0 - A baseline scenario involving no new policy initiatives. The results of this scenario are used as a benchmark against which the impacts upon the energy system of more aggressive policy scenarios can be evaluated.

(2) Scenario I - Substantial improvements in end use efficiencies, and some supply enhancement.

(3) Scenario II - Major synthetics fuel capability is introduced.

(4) Scenario III - Intensive electrification with improved efficiencies in electricity conversion, transmission, and distribution, and widespread use of electric automobiles.

(5) Scenario IV - Limited nuclear power (converter reactor production constrained to 200,000 megawatts) coupled with constraints on coal electric which force synthetic production. Industrial efficiencies of Scenario I are assumed.

(6) Scenario V - Most optimistic. All conservation initiatives in effect and all technologies available at most optimistic levels.

ERDA analyzes each of these scenarios using a combination of expert judgment and a model of the energy production, conversion, and utilization system for the United States. In this section we present the ERDA model and describe how it was applied.

2.1 The ERDA Model

In analyzing the alternative energy supply and demand scenarios, ERDA has employed a computerized analysis procedure and a linear programming model, both of which were developed at the Brookhaven National Laboratory. The computerized energy analysis procedure, called the Reference Energy System (RES) involves a network representation of the energy system relating end use demand to intermediate conversion and transport activities and, ultimately, to the supply of such primary energy types as coal, gas, oil, and uranium. The RES may be used to organize historical data for the energy system and to facilitate the use of historical data, judgment, and forecasts from other models in forecasting and analyzing future energy systems. In addition, the structure and associated data of the RES may be used in a linear programming model of the energy system designed to determine the least-cost combination of energy activities necessary to meet a given level of final demand. This linear programming model, the Brookhaven Energy System Optimization Model (BESOM) incorporates an assumed technological representation of the U.S. energy system as constraints together with other such constraints as environmental effects, primary energy type availability, and end use demands for energy.

In the following two sections we describe and evaluate the RES and BESOM model in sufficient detail to acquaint the reader with the types of problems for which each of these models was designed. We then discuss how the models were employed by ERDA.

2.1.1 The Reference Energy System (RES) [1/]

The RES provides an engineering or process representation of the U.S. energy system. The system is characterized by a network of technologies for the extraction of primary energy types, and technologies for conversion and refining, transport, and final utilization. The detail of the network representation is presented in Figures 4-1, and B-1 through B-12 of ERDA-48. Figures 4-1 and B-1 are reproduced to facilitate the following discussion.

Consider Figure 4-1. The process of extraction for primary energy types is represented on the left-hand side of the network, while the end use demands are represented on the right-hand side. Primary inputs and end use demand are related by a series of intermediate activities, including refining and conversion, transport, conversion, transmission and distribution, and delivery to the utilizing device. The nodes in the network represent the intermediate activity. The nodes are connected by arcs to which are attached two numbers. The first number represents the flow of energy between two nodes, while the second number (always in parenthesis) represents the conversion efficiency of the intermediate activity. In figure 4-1, the use of coal in the production of electricity, it is seen that of the 6.3 Quads of electricity produced in 1972, 2.7 Quads were derived from coal. This amount of coal-generated electricity required the delivery of 7.94 Quads of coal to the electric utility sector (2.7/.34 = 7.94). Thus, of the 14.1 Quads of coal produced in the United States in 1972, 56% was used in the production of electricity.

Comparing Figure 4-1 with Figure B-1, we find that the representation of the energy system used by ERDA to present its Scenario 0 forecast for 1985 is significantly more complicated than the summary representation for 1972. In fact, the network may be as complicated as the data sources relating to the various technologies will permit. For example, Brookhaven has constructed supporting data for approximately 200 distinct end use categories as well as much more complicated representations of extraction, conversion, and transport technologies. The network detail presented in Figure B-1 is significantly

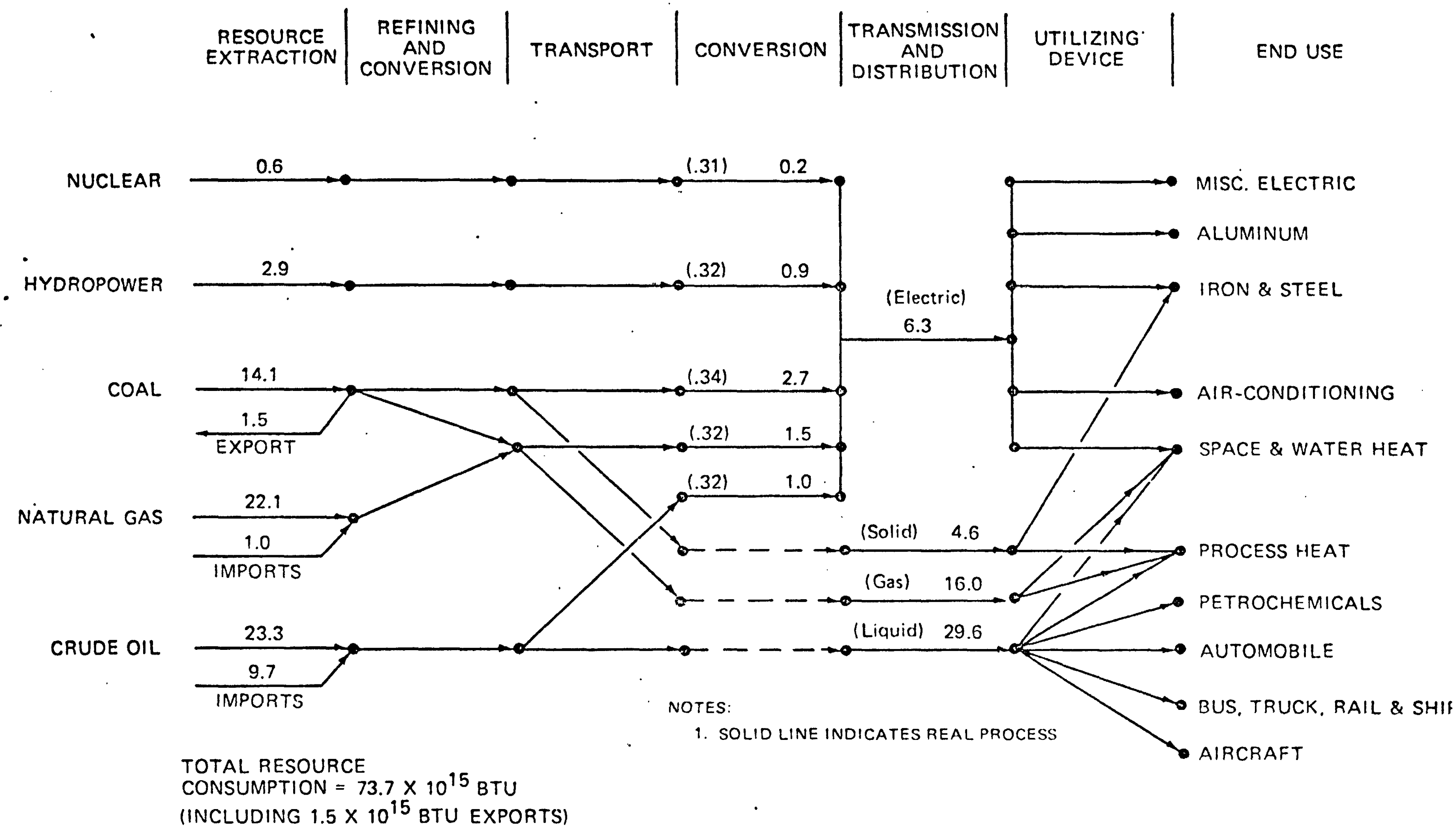

Figure 4–1. Reference Energy System 1972

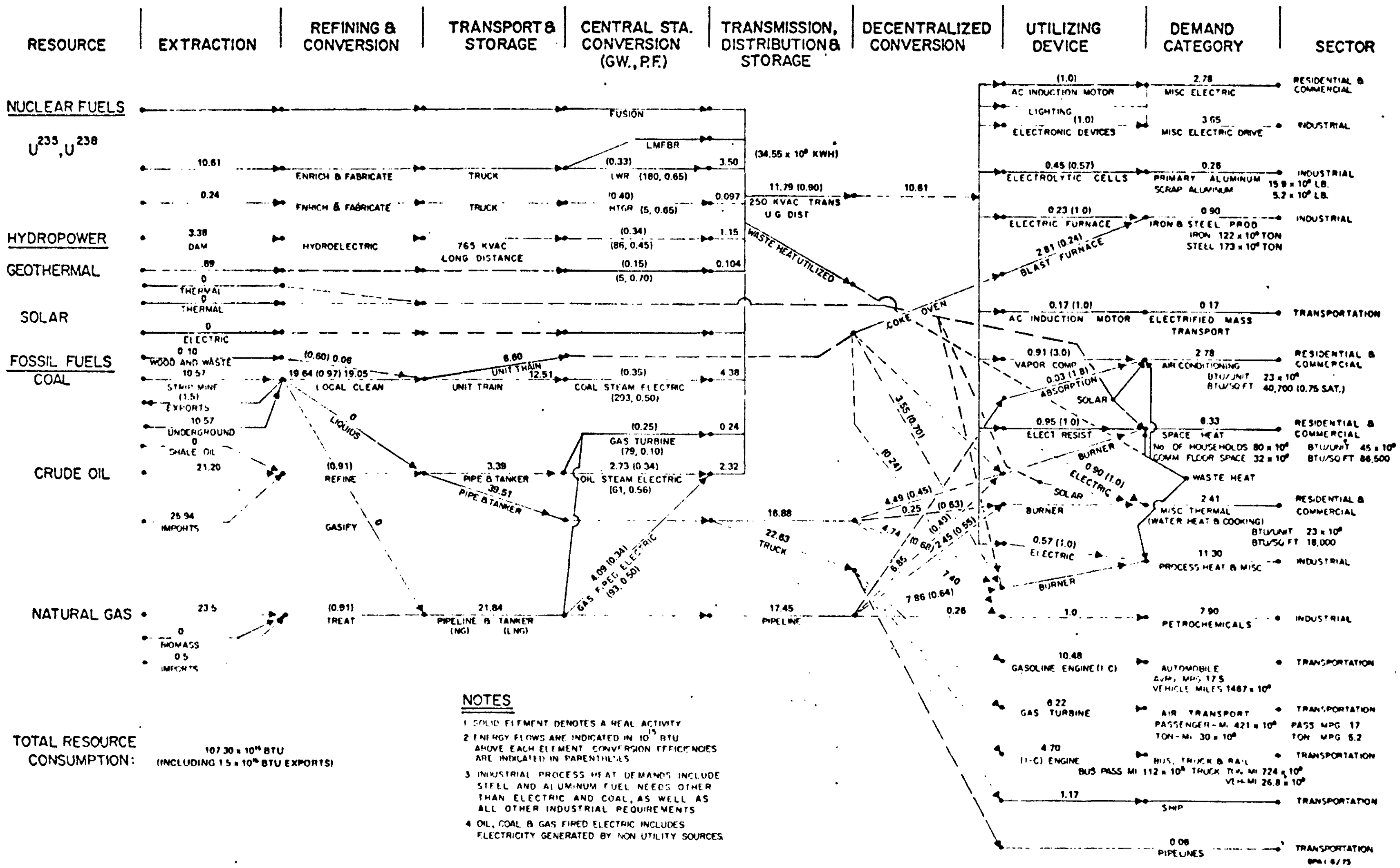

Figure B—1. Scenario O No New Initiatives, Year 1985 aggregated from the detail of the computerized version of the RES and, presumably, the actual level of detail that ERDA used in developing and analyzing each of the six scenarios.

The end use demand classification is of interest since it emphasizes the functional nature of energy demand by major consuming sector. For example, total residential and commercial demand for energy is composed of demands for space heat, air conditioning, miscellaneous thermal, and miscellaneous electricity. This classification of demand is useful, since it permits an explicit consideration of the alternative technologies which might be used in meeting a particular functional demand. The difficulty with the functional classification of end use demand is that historical data on energy consumption is not currently obtained and reported. The only efforts to compile such data are a study by Stanford Research Institute [3] and the continuing efforts of Brookhaven. No federal statistical program exists to measure and report the quantities and values of U.S. energy consumption by major function. Thus the process of developing models of functional energy demand that are sensitive to delivered prices and other variables which would be expected to influence energy demand is greatly complicated. In fact, no such model has yet been developed.

The RES has been used by Brookhaven and ERDA to provide a discipline for the organization of historical data, and to facilitate preparing, presenting, and interpreting forecasts of future energy systems. To see how RES may be used in forecasting future energy systems, consider again Figure 4-1. If we assume that for some future period, say 1985, the same proportional distribution of primary energy types will take place among the various intermediate activities and end use final demands, and if we have an independent forecast of the end use final demand for 1985, then the 1972 proportional distribution factor may be applied to the end use final demand to "fill out" the network for 1985. This procedure would represent the simplest, most mechanical use of the RES and its associated data base in producing a forecast for some future energy system.

The second way in which the RES might be used in preparing an energy system forecast involves exploiting the organizational structure of the system to facilitiate organization and presentation of expert opinion, or the forecasts of explicit models for some subcomponent of the network. For example, we might obtain a forecast of end use final demand from an econometric model and a forecast of the production of primary energy input from a separate model. The RES would provide a framework for relating these two seemingly independent forecasts through a working-out of the intermediate flows required. Such an exercise would involve combining the use of historical information on proportional distributions of energy types through the system with judgmental forecasts of expected future conditions, efficiencies, and so on which would require adjustment to the historical factors. The significant contribution of the RES is to force complete internal consistency in developing and presenting forecasts of future energy systems. This tool is especially useful when the analyst is attempting to incorporate new technologies into the energy system for which there exists no historical experience. The process of adding nodes and arcs and associated efficiencies to the network and working out the analysts' projections of the changes in flows is extremely useful in building an understanding of the system.

2.1.2 The Brookhaven Energy System Optimization Model (BESOM)

An alternative appraoch to determining how the mix of technologies used is affected by changes in costs or introduction of a new technology is to solve an explicit optimization problem in which the least cost combination of technologies is chosen subject to contraints on primary energy input availabilities, conversion and transport capacities, end use demands, and other constraints such as permissable environmental impacts levels. The Brookhaven National Laboratory has developed an optimization model, BESOM, to solve this problem [4].

BESOM may be interpreted as a "BTU equilibrium" system in which energy is treated as an input factor in production processes for final demand. Rather than using derived demand equations arising from many different processes (e.g., household demand for natural gas arises from space heating, cooking, water heating, and air conditioning), it considers each production process separately. The production process is described by its technological coefficients. Factor demand (demand for industrial petroleum products, natural gas, and so on) for the individual process will then depend on the level of final product demand and the individual factor prices. 3/ For example, consider the final demand for a certain quantity of water to be heated. In BESOM, while this final demand level is set exogenously, the demand may be met through using natural gas, distillate oil, electricity, or coal. The model evaluates the cost of each method for satisfying the demand given the different technologies and the factor input prices. Under cost minimization the least expensive method will be chosen, with the actual factor demand determined by the input-output coefficient of the chosen technology.

The advantage of this framework for calculating energy demands is evident when an evaluation of a new technology or price change is needed. A new technology may be described by its input-output coefficients and costs, and the optimization program re-solved to evaluate the importance of the new technique. It will be adopted if at the new set of equilibrium prices the cost of producing the desired output quantity is less than the cost of the old techniques. Likewise, if an exogenous price, e.g., imported oil, changes then factor demands will change in response to cost minimization at the new factor prices.

In its BTU equilibrium framework the model has a very careful treatment of supply efficiency in producing BTU's, transport costs and transmission loss of BTU's, and the utilization efficiency of BTU's in meeting final demand. Thus a ton of coal can be transported to a house and used in a furnace to heat water, it can be turned into electricity and transmitted to the house and used in a water heater, or alternatively it can be converted into methanol which is then transported and used on location. Since the efficiences of each of these alternative technologies are carefully evaluated, the true costs of using coal to eventually heat water may be accurately assessed. This technology assessment is seen to be the comparative advantage of a BESOM-type model.

The BTU equilibrium framework with an explicit technological bias has an advantage over the traditional aggregate derived demand framework in long-range assessments for two reasons. Most important, the derived demand framework is unable to handle new technologies. Since the technology has not been observed before, the previously estimated equations could not have taken its effects into account. A second major advantage is that when relative prices change, especially with large magnitude, the aggregate derived demand will change in response to the changes of its many component parts. While for small price changes the aggregate equations may do well since one is considering the elasticities, for large changes much different patterns of substitution will likely exist for the different components of demand. In this case the aggregate equations will probably be inferior.

The most important sensitivity of this type of energy processing model is the need for a full and accurate description of the technology. The "engineering coefficients" which describe the processes must be accurate, or seriously distorted results will occur. Also all possible technologies, not just those techniques currently in use, must be input into the model. When prices change or new technologies are introduced which can change prices, a technique which is currently uneconomical and not in use may well be found to be economical at the new prices.

An explicit description of the BESOM model which is solved as a linear program is

(1) $\min \sum_j c_j x_j$ (c_j = cost/BTU for this activity, x_j = BTU's delivered from jth activity)

subject to:

(2) $\sum_j \frac{1}{e_{uj}} x_j \leq S_u$ (e_{uj} = BTU/physical unit, S_u = total resource supply in physical units, $u = 1,\ldots n$)

(3) $\sum_j d_{vj} x_j = D_v$ (d_{vj} = units of final demand/BTU, D_v = level of final demand, $u = 1,\ldots m$)

(4) $\sum_j f_{wj} x_j \leq B_w\ ,\ x_j \geq 0$ (environmental constraints, $w = 1,\ldots l$)

When considering use of the BESOM, a number of limitations of the model should be kept in mind. First, the model as currently formulated assumes both primary energy supply and end case demand to be exogenous while in reality they should be a function of prices and other variables which affect decisions as to the level and distribution of energy to be purchased. Most of the problem could be overcome by making both a function of prices so, for instance, the amount of natural gas supplied would be $S_{gas} = F(P_{gas}, P_{oil} \cdot \cdot \cdot)$, where P_{gas} and P_{oil} are the shadow prices of gas and oil from the optimum solution. Problems of joint products would be present but would be represented in a more complicated framework. Therefore, instead of having both supply and demand being price inelastic, price responsiveness could be introduced as a series of step functions in the standard LP manner.

Another problem in the current version of BESOM is the incorrect treatment of electricity. Electricity is currently treated only as a primary energy source along with solar energy, oil, coal, etc. However, electricity conversion is also a processing activity which converts primary energy sources into an intermediate product which is in turn used as a factor input into production for final demand. Thus, in the present version the shadow price of coal being used to produce electricity will not be equal to the shadow price of coal used as a factor input in other sectors of the economy. A corrent cost minimizing solution is not guaranteed unless the value of primary inputs is assessed at the same price everywhere in the economy. The BESOM model does not currently insure that this optimization condition is satisfied.

Another shortcoming of the BESOM model is that it is basically a two factor model of production since it considers only energy and capital costs. For many of the demand categories considered in the model, this simplification is probably not that important since little opportunity for factor substitution exists. Yet, in many processes in industry factor substitution possibilities do exist, and consequently levels of factor demand depend on the prices of all inputs. Historically, production processes have become less labor intensive as the real wage rose relative to other input prices. Thus in a long-run simulation (up to 2000), changes in relative input prices must be taken into account in calculating factor demands. Given the partial equilibrium nature of the BESOM model, it seems ill-suited to do such projections. A general equilibrium framework must be used. However, for technology assessment at current prices or to assess relative changes along an assumed production trajectory, the BESOM model has the advantage of correctly treating energy as an input factor in production for final demand rather than as a good desired for itself. It is this explicit treatment which is the contribution of the model since the explicit representation of technologies permits a careful assessment of their costs with different input prices.

2.1.3 ERDA Use of the RES and BESOM

ERDA's approach to developing and analyzing the alternative scenarios of future energy systems is summarized in Appendix B [ERDA-48] as follows:

> "Demand and supply inputs were developed independently on the basis of engineering, demographic and economic data. Each scenario presented in the report was initially generated by a judgmental procedure, and then the computer model was constrained to produce similar results providing as output the environmental and related residuals. In addition, less constrainted optimization runs were made for comparison of new technologies. The strength of the approach lies in the complementarity of the mechanical optimization model and the judgmental hand approach."

Thus the RES was used to facilitate development of the levels of factor demand for each end use final demand. The BESOM was used to find a set of constraints which produced the judgmental forecast and to calculate environmental impacts and "residentuals" including the average resource cost per million BTU's delivered to final demand. Sensitivity runs were executed in order to provide additional information on the breakeven prices for the new and emerging technologies. This information was used in establishing the ranking of R, D&D technologies presented in Table 6-2 [ERDA-48].

ERDA develops two end use demand forecasts which are used as input to the six scenario analyses. The basic demand scenario is generated using assumptions about such market size variables as the expected housing stock, commercial floor space industrial output levels, and vehicle, passenger and ton miles for transportation. Associated with some of these end use demands are efficiencies such as average miles-per-gallon for automobiles. A second demand projection has been developed by ERDA under more optimistic assumptions concerning these efficiencies.

Prices, incomes, or other macroeconomic and demographic variables are not used in generating the demand forecast, or are assumed to be summarized in the market size variables that are used. The assumption is made that there is "...a continuation of historical trends by use sector modified to reflect recent price increases" [ERDA-48, S-5].

The fact that end use demands are assumed fixed for all scenarios, except where the scenarios involves an adjustment of an end use utilization efficiency, means that demands are independent of the relative prices of energy both between energy types and between energy and other factors of production, such as capital, labor, and other material inputs.

3. EVALUATION OF ERDA METHODOLOGY AND RESULTS

In this section we review and evaluate the ERDA methodology. Our purpose is to identify weaknesses in the ERDA approach and to suggest alternatives or means for correcting these weaknesses. Before doing this, it is useful to put our remarks in perspective by considering why ERDA requires a demand forecast. As we see it, ERDA's basic problem is to choose a portfolio of R, D&D projects with a high probability of significantly increasing our national flexibility in choosing desirable future energy systems. In developing such a portfolio a forecast of future energy demands is required in order to establish the cut-off point at which development of additional technologies is non-profitable in the sense that the additional "flexibility" will never be used. If the projected demand increased substantially, then more technologies become profitable in this sense. Technology developments should be supported to a level necessary to satisfactorily ensure against underestimating future demands. Viewed this way it seems clear that the paramont modeling and data development problem for ERDA is in developing the engineering data and input-output coefficients for each of the competing technologies. Accurate demand forecasting is, of course, important but clearly is a secondary consideration compared with properly characterizing the competing technologies. In our opinion, ERDA's emphasis in the first plan is correctly placed. It will remain for future efforts to deal with the important secondary problems of analysis.

3.1 Evaluation of ERDA Methodology

From a logical point of view, we find the ERDA analysis of demand to be correct, given the assumptions they choose to make, and excepting the incorrect treatment of electricity in BESOM. Given the method in which BESOM was used, this problem does not contribute any fundamental error to the ERDA analysis. We take issues, however, with the assumptions of the method. First, assuming perfectly inelastic demand functions seems unwarranted. This assumption was necessary for two reasons. First, the assumption is necessary in order to avoid having to directly incorporate into the analysis assumptions about the world price of oil. Secondly, the RES and BESOM will not presently accommodate a model of energy demand which is price sensitive. The reason for this is that if such a model existed, a procedure would have to be implemented in which the shadow prices of the linear programming solution for the supply technologies could be used to adjust demand prices and calculate corresponding new end use demands. This procedure, analagous to that used by FEA in the Project Independence Report, is an iterative one for obtaining an equilibrium solution for energy flows and relative energy prices. There is no conceptual reason why the BESOM could not be modified to accommodate such a price sensitive demand model.

An analogous argument can be made for including price sensitive supply models of primary energy factors. Again, no conceptual obstacle exists to incorporating such models into the BESOM framework.

The ERDA demand projections are also independent of the prices of non-energy goods and services, as well as being independent of any explicit assumptions about future macroeconomic and demographic conditions. As noted previously, we believe this to be a significant problem in the industrial sector where energy as an input competes with other factors of production, such as capital, labor and other material inputs. Accommodating this modification would require that BESOM be integrated with a general equilibrium macroeconomic model of the U.S. economy, which included a complete factor demand model, as well as primary energy input supply models. We believe that such an effort should be high on ERDA's agenda of research to improve its capability to prepare and assess the national energy R,D&D plan.

The ERDA analysis contains no regional sensitivity in either the production of or demand for energy. Some regional analysis is implicit in that transportation costs are accounted for in both RES and BESOM, but these costs are national averages associated with each of the transport modes, and do not reflect an explicit statement of regional production and demand. In long range simulation and analysis of the energy system, some account of factors affecting regional conditions for energy supply and demand seems essential. Again, there is no conceptual reason why the RES and BESOM cannot be accommodated to a regional classification of data. Certainly the FEA effort demonstrates the possibility of this approach.

Perhaps the most serious limitation of the ERDA analysis is the treatment of conservation. Conservation initiatives are represented in the forecast by adjusting utilization and conversion device efficiencies. Presumably these changes in efficiencies come about due to the implementation of conservation policies which are reflected in changes in technology costs or by institutional changes and prohibitions. However, the policy initiatives which would induce the particular set of efficiency changes assumed are not discussed. This has two important consequences. First, the possibility of achieving these changes in efficiencies is unknown, since we have no explicit statement of the proposed program. As an exercise any demand scenario we might desire can be achieved by finding a suitable set of utilization efficiencies. We do not suggest that the conservation scenario is arbitrary, but rather that insufficient information is provided concerning its possibility of implementation. The second problem is that the costs associated with the program necessary to induce the projected changes in efficiencies cannot be calculated. Thus the changes in technology costs, either to existing or new technologies, necessary to achieve the changes are not included in the system. The basic consequence of this is that there is no way to systematically compare on a cost basis the gains due to conservation initiatives versus the gains due to supply initiatives. This is a fundamental difficulty since ERDA's key problem is to be able to provide comparative analyses of competing technologies.

3.2 Evaluation of Results

In order to facilitate comparing ERDA scenario results with other forecasts, we present in Table I a re-compilation of the information contained in the RES network representations, Figures B-1 through B-12. In particular, we have accumulated the energy required by primary energy input type to support the final demand for each of the major consuming sectors. All the information concerning the intermediate transformation and transportation of energy type is suppressed. These summary tables are comparable in format and definition to those developed by the Department of the Interior in preparing and presenting its energy balance forecast, and adopted by the FEA to summarize its forecast.

We compare the ERDA forecast scenarios with two other official government long-range forecasts, including the pre-embargo Department of the Interior forecast and a series of forecasts made by the FEA in the Project Independence report. The Department of the Interior forecast (DOI) was prepared and published in 1972. It represents an effort to project primary energy supply and demand by major consuming sector for the period 1975 - 2000. The forecast assumes a relatively high rate of growth for real output in the economy (approximately 4% per annum) and stable relative prices for energy. At the time the forecast was made, the price per barrel of crude oil was approximately $3.50.

The FEA forecasts represent an effort to assess the effects of the embargo and alternative federal government policies strategies for the period 1977, 1980, and 1985. The FEA forecasts proceed by making baseline forecasts under the assumption of $7.00 and $11.00 prices per barrel of crude oil (1973 dollars). They then analyzed the effects of a number of conservation initiatives upon their baseline forecast (conservation scenario), the effects of accelerated development of supply possibilities and technologies (accelerated development

TABLE I

United States Total Gross Energy Consumption of Energy Resources by Major Sources and Consuming Sectors. ERDA Scenarios 0, I, II, III, IV, V for the Years 1985 and 2000. (All units in quadrillions of BTU's)

SECTOR	Coal[1]	Oil[2]	Gas[3]	Nuclear	Hydro & Other[4]	Total Gross Energy[5]	Synthetics Dist.[6] Oil	Synthetics Dist.[6] Gas	Elec. Dist.[9]	Misc. Thermal[7]	Total Direct Fuel[8]
Scenario 0, 1985											
Household & Commercial	--	5.21	10.25	--	--	15.46			6.16		21.62
Industrial	6.80	13.34	8.92	--	--	29.06			5.44		34.50
Transportation	--	24.87	--	--	--	24.87			0.19		25.06
Electrical Generation	12.84	3.72	4.82	10.85	4.08	36.31			--		21.38
Synthetics	--	--	--	--	--	--			--		--
Total Consumption	19.64	47.14	23.99	10.85	4.08	105.70			11.79		102.56
Domestic Production	21.14	21.20	24.00	10.85	4.08	81.27			11.79		78.13
Net Imports	-1.50	25.94	--	--	--	23.43			--		24.43
Scenario 0, 2000											
Household & Commercial	--	7.59	8.23	--	--	15.82			10.49		26.31
Industrial	16.01	23.20	4.97	--	--	44.18			12.82		57.00
Transportation	--	35.27	--	--	--	35.27			0.25		35.52
Electrical Generation	16.38	4.47	2.20	40.49	5.05	68.59			--		23.05
Synthetics	--	--	--	--	--	--			--		--
Total Consumption	32.39	70.53	15.40	40.49	5.05	163.86			23.56		141.88
Domestic Production	33.89	12.20	15.40	40.49	5.05	107.03			23.56		85.05
Net Imports	-1.50	58.33	--	--	--	56.83			--		56.83
Scenario I, 1985											
Household & Commercial	--	2.05	9.28	--	--	41.33			5.70	0.55	17.58
Industrial	5.92	6.89	13.91	--	--	26.72			5.03	0.30	32.05
Transportation	--	22.58	--	--	--	22.58			0.19	--	22.77
Electrical Generation	12.28	3.06	3.30	10.86	4.11	33.61			--	--	18.64
Synthetics	--	--	--	--	--	--			--	--	--
Total Consumption	18.20	34.58[A]	26.49[A]	10.86	4.11	94.24			10.92	0.85	90.19
Domestic Production	19.70	24.10	26.50	10.86	4.11	85.27			0.92	0.85	81.22
Net Imports	-1.50	10.49	--	--	--	8.07[A]			--	--	8.97[A]

1 See footnotes at end of table.

TABLE I (cont.)

United States Total Gross Energy Consumption of Energy Resources by Major Sources and Consuming Sectors. ERDA Scenarios 0, I, II, III, IV, V for the Years 1985 and 2000. (All units in quadrillions of BTU's)

SECTOR	Coal[1]	Oil[2]	Gas[3]	Nuclear	Hydro & Other[4]	Total Gross Energy[5]	Synthetics Dist.[6] Oil	Synthetics Dist.[6] Gas	Elec. Dist.[9]	Misc. Thermal[7]	Total Direct Fuel[8]
Scenario I, 2000											
Household & Commercial	--	0.93	10.33	--	--	11.26			6.16	2.50	19.92
Industrial	13.01	9.13	12.47	--	--	34.61			7.76	5.00	47.37
Transportation	--	27.86	--	--	--	27.86			0.25	--	28.11
Electrical Generation	12.42	2.40	--	20.40	5.05	40.27			--	--	14.82
Synthetics	--	--	--	--	--	--			--	--	--
Total Consumption	25.43	40.32	22.80	20.40	5.05	114.00			14.17	7.50	110.22
Domestic Projection	26.93	19.70	22.80	20.40	5.05	94.88			14.17	7.50	91.10
Net Imports	-1.50	20.62	--	--	--	19.12			--	--	14.12
Scenario II, 1985											
Household & Commercial	--	4.18	10.53	--	--	14.71	0.05	0.36	6.16	0.10	21.38
Industrial	6.80	10.00	11.37	--	--	28.17	0.11	0.39	5.44	0.30	34.41
Transportation	--	24.56	--	--	--	24.56	0.28	--	0.19	--	25.03
Electrical Generation	12.90	3.59	4.64	10.85	4.07	36.05	0.04	0.16	--	--	21.33
Synthetics	2.14	--	--	--	--	2.14	--	--	--	--	2.14
Total Consumption	21.84	42.33	26.54[A]	10.85	4.07	105.63	0.48	0.91[A]	11.79	0.40	104.29
Domestic Projection	23.34	25.10	26.55	10.85	4.07	89.91	0.48	0.92	11.79	0.40	88.58
Net Imports	-1.50	17.23[A]	--	--	--	15.72	--	--	--	--	15.71
Scenario II, 2000											
Household & Commercial	--	2.73	8.50	--	--	11.23	0.63	1.22	10.31	1.00	24.39
Industrial	11.44	11.51	13.90	--	--	36.85	2.64	2.00	12.62	2.00	56.11
Transportation	--	28.16	--	--	--	28.16	6.47	--	0.25	--	34.88
Electrical Generation	15.68	3.31	1.90	40.49	4.05	65.43	0.76	0.27	--	--	21.92
Synthetics	21.21	--	--	--	--	21.21	--	--	--	--	21.21
Total Consumption	48.33	45.71	24.30	40.49	4.05	162.88	10.50	3.49[A]	23.18	3.00	158.51
Domestic Projection	49.83	27.70	24.30	40.49	4.05	146.37	10.50	3.50	23.18	3.00	142.01
Net Imports	-1.50	18.01	--	--	--	16.51	--	--	--	--	16.51

[1] See footnotes at end of table.

TABLE I (cont.)

United States Total Gross Energy Consumption of Energy Resources by Major Sources and Consuming Sectors. ERDA Scenarios 0, I, II, III, IV, V for the Years 1985 and 2000. (All units in quadrillions of BTU's)

SECTOR	Coal[1]	Oil[2]	Gas[3]	Nuclear	Hydro & Other[4]	Total Gross Energy[5]	Synthetics Dist.[6] Oil	Synthetics Dist.[6] Gas	Elec. Dist.[9]	Misc. Thermal[7]	Total Direct Fuel[8]
Scenario III, 1985											
Household & Commercial	--	2.56	9.36	--	--	11.92			6.98	0.40	19.30
Industrial	5.76	9.22	13.64	--	--	28.62			5.44	0.45	34.51
Transportation	--	24.40	--	--	--	24.40			0.37	--	24.77
Electrical Generation	12.90	5.40	3.50	13.21	4.84	39.85			--	--	22.86
Synthetics	--	--	--	--	--	--			--	--	--
Total Consumption	18.66	41.58	26.50	13.21	4.84	104.79			12.79	0.85	101.44
Domestic Projection	20.16	24.10	26.50	13.21	4.84	88.81			12.79	0.85	85.40
Net Imports	-1.50	17.48	--	--	--	15.98			--	--	15.98
Scenario III, 2000											
Household & Commercial	--	2.75	5.96	--	--	8.71			10.39	2.50	21.60
Industrial	10.12	6.24	14.65	--	--	31.01			16.50	5.00	52.51
Transportation	--	33.00	--	--	--	33.00			1.22	--	34.22
Electrical Generation	18.94	4.48	2.20	44.44	12.34	--			--	--	--
Synthetics	--	--	--	--	--	--			--	--	--
Total Consumption	29.06	46.47	22.81	44.44	12.34	82.40			28.11	7.50	--
Domestic Projection	30.57	19.70	22.80	44.44	12.34	--			28.11	7.50	--
Net Imports	-1.50	26.77	--	--	--	--			--	--	--
Scenario IV, 1985											
Household & Commercial	--	4.57	10.04	--	--	14.61	0.05	0.35	6.16	0.20	21.37
Industrial	4.55	10.86	12.24	--	--	27.65	0.12	0.42	5.03	0.25	33.47
Transportation	--	24.58	--	--	--	24.58	0.28	--	0.19	--	25.05
Electrical Generation	11.78	2.52	4.27	10.85	6.70	36.12	0.03	0.15	--	--	18.75
Synthetics	2.15	--	--	--	--	2.15	--	--	--	--	2.15
Total Consumption	18.48	42.53	26.55	10.85	6.70	105.11	0.48	0.92	11.38	0.45	100.79
Domestic Projection	19.98	25.10[A]	26.55	10.85	6.70	89.18	0.48	0.92	11.38	0.45	84.86
Net Imports	-1.50	17.43	--	--	--	15.93	--	--	--	--	15.93

[1] See footnotes at end of table.

TABLE I (cont.)

United States Total Gross Energy Consumption of Energy Resources by Major Sources and Consuming Sectors. ERDA Scenarios 0, I, II, III, IV, V for the Years 1985 and 2000. (All units in quadrillions of BTU's)

SECTOR	Coal[1]	Oil[2]	Gas[3]	Nuclear	Hydro &[4] Other	Total Gross Energy[5]	Synthetics Dist.[6] Oil	Synthetics Dist.[6] Gas	Elec. Dist.[9]	Misc. Thermal[7]	Total Direct Fuel[8]
Scenario IV, 2000											
Household & Commercial	--	4.60	10.06	--	--	14.66	1.00	1.45	7.25	2.50	26.86
Industrial	9.03	13.02	12.34	--	--	34.39	2.83	1.78	8.52	2.00	49.52
Transportation	--	28.46	--	--	--	28.46	6.19	--	0.25	--	34.90
Electrical Generation	14.13	2.16	1.90	11.42	6.70	53.28	0.47	0.27	--	--	18.43
Synthetics	21.21	--	--	--	--	21.21	--	--	--	--	21.21
Total Consumption	44.37	48.24	24.30	11.42	6.70	152.00	10.49[A]	3.50	16.02	4.50	151.42
Domestic Projection	45.87	27.70[A]	24.30	11.42	6.70	132.96	10.50	3.50	16.02	4.50	132.39
Net Imports	-1.50	20.54[A]	--	--	--	19.04	--	--	--	--	19.03
Scenario V, 1985											
Household & Commercial	--	2.02	8.98	--	--	11.00	0.03	0.31	5.70	0.55	17.59
Industrial	5.92	5.79	14.39	--	--	26.10	0.08	0.50	5.03	0.30	32.01
Transportation	--	22.11	--	--	--	22.11	0.32	--	0.24	--	22.67
Electrical Generation	9.80	3.01	3.18	13.22	4.84	34.05	0.04	0.11	--	--	16.14
Synthetics	2.15	--	--	--	--	2.15	--	--	--	--	2.15
Total Consumption	17.27	32.93	26.55	13.22	4.84	95.41	0.47[A]	0.92	10.97	0.85	90.56
Domestic Projection	19.37	25.10[A]	26.55	13.22	4.84	89.04	0.48	0.92	10.97	0.85	84.20
Net Imports	-1.50	7.83[A]	--	--	--	6.37	--	--	--	--	6.36
Scenario V, 2000											
Household & Commercial	--	0.62	8.92	--	--	9.54	0.28	1.28	6.16	2.50	19.76
Industrial	11.73	3.54	15.37	--	--	30.64	1.58	2.22	7.76	5.00	47.20
Transportation	--	25.67	--	--	--	25.67	8.03	--	0.94	--	34.64
Electrical Generation	8.69	1.38	--	7.85	10.57	28.49	0.62	--	--	--	10.69
Synthetics	21.21	--	--	--	--	21.21	--	--	--	--	21.21
Total Consumption	41.63	31.21	24.29[A]	7.85	10.57	115.55	10.51[A]	3.50	14.86	7.50	133.50
Domestic Projection	43.13	27.70	24.30	7.85	10.57	113.55	10.51	3.50	14.86	7.50	131.50
Net Imports	-1.50	3.51	--	--	--	2.00	--	--	--	--	2.00

[1] Includes wood and waste
[2] Includes shale oil
[3] Includes biomass
[4] Includes solar electricity and geothermal electricity
[5] Sum of columns 1-4
[6] Distributed in final form as oil and gas
[7] Solar thermal, geothermal, and waste heat
[8] Sum of colums 1,2,3,4,8,9,10
[9] Electricity measured at central generating station
[A] Error attributable to rounding

Summary of FEA Scenario Forecasts for 1985 Assuming $11.00 World Oil Price[1]

(Quadrillions of BTU's)

Consuming Sector	Coal[2]	Petroleum[3]	Natural Gas	Total Fossil Fuel	Nuclear Power	Other	Total Gross Energy Inputs	Other Intermediate Syn. Dist.	Total Four Sector Inputs	Utility Electric Consumed	Total Three Sector Inputs
Business-As-Usual Without Conservation											
Household & Commercial	.1	5.9	10.9	16.9			16.9	0.0	16.9	8.2	25.1
Industrial	6.3	8.5	10.0	24.9			24.9	0.0	24.9	4.1	29.0
Transportation	0.0	20.6	1.4	21.9	12.5	4.8	21.9		21.9	0.0	22.0
Electrical Generation	16.4	3.0	2.5	21.9			39.2		39.2	(12.3)	
Synthetics	0.0		0.0				0.0	0.0			
TOTAL	22.9	38.0	24.8	85.6	12.5	4.8	102.9	0.0	102.9	0.0	76.1
Business-As-Usual With Conservation											
Household & Commercial	.1	5.4	9.9	15.4			15.4	0.0	15.4	7.2	22.6
Industrial	6.1	8.1	9.9	24.1			24.1	0.0	24.1	3.9	27.9
Transportation	0.0	17.7	1.4	19.1			19.1		19.1	0.0	19.1
Electrical Generation	13.4	2.4	2.5	18.3	12.5	4.8	35.6		35.6	(11.1)	
Synthetics	0.0						0.0	0.0			
TOTAL	19.7	33.5	23.7	76.9	12.5	4.8	94.2	0.0	94.2	0.0	69.6
Accelerated Supply Without Conservation											
Household & Commercial	.1	6.0	11.3	17.4			17.4	.1	17.4	8.1	25.5
Industrial	6.3	8.5	10.4	25.2			25.2	.1	25.2	0.0	29.3
Transportation	0.0	21.1	1.4	22.4			22.4		22.4	0.0	22.5
Electrical Generation	14.3	2.5	2.5	19.3	14.7	4.8	38.8		38.8	(12.1)	
Synthetics	.4			.4			.4	(.1)			
TOTAL	21.1	38.1	25.5	84.7	14.7	4.8	104.2	0.0	103.9	0.0	77.2

Accelerated Supply with Conservation

Household & Commercial	.1	5.5	10.3	15.9			15.9	.1	16.0	7.1	23.1
Industrial	6.0	8.1	10.3	24.4			24.4	.1	24.4	3.8	28.2
Transportation	0.0	18.6	1.4	20.0			20.0		20.0	0.0	20.0
Electrical Generation	10.0	3.5	2.7	16.1	14.7	4.8	35.6		35.6	(10.9)	
Synthetics	.4			.4			.4	(.1)			
TOTAL	16.4	35.7	24.6	76.7	14.7	4.8	96.3	0.0	96.0	0.0	71.3

[1]Source is FEA Project Independence Report. Prices are constant 1973 dollars.

[2]Includes anthracite, bituminous and lignite.

[3]Petroleum products refined and processed from crude oil, including still gas, liquified refinery gas, and natural gas liquids.

Summary of FEA Scenario Forecasts for 1985 Assuming $7.00 World Oil Price[1]

(Quadrillions of BTU's)

Consuming Sector	Coal[2]	Petroleum[3]	Natural Gas	Total Fossil Fuel	Nuclear Power	Other	Total Gross Energy Inputs	Other Intermediate Syn. Dist.	Total Four Sector Inputs	Utility Electric Consumed	Total Three Sector Inputs
Business-As-Usual Without Conservation											
Household & Commercial	.1	7.1	10.7	17.9			17.9	0.0	17.9	8.1	25.9
Industrial	6.3	10.2	9.3	25.8			25.8	0.0	25.8	4.6	30.4
Transportation	0.0	23.2	1.4	24.5			24.5		24.5	0.0	24.6
Electrical Generation	13.5	7.4	2.7	23.6	12.5	4.8	40.9		40.9	(12.7)	
Synthetics	0.0			0.0			0.0	0.0			
TOTAL	19.9	47.9	23.9	91.8	12.5	4.8	109.1	0.0	109.1	0.0	80.9
Business-As-Usual with Conservation											
Household & Commercial	.1	6.5	9.6	16.3			16.3	0.0	16.3	7.0	23.3
Industrial	5.9	9.9	8.9	24.6			24.6	0.0	24.6	4.4	29.1
Transportation	0.0	18.9	1.4	20.3			20.3		20.3	0.0	20.3
Electrical Generation	10.7	7.3	2.7	20.7	12.5	4.8	38.0		38.0	(11.5)	
Synthetics	0.0			0.0			0.0				
TOTAL	16.7	42.6	22.5	81.9	12.5	4.8	99.2	0.0	99.2	0.0	72.7
Accelerated Supply Without Conservation											
Household & Commercial	.1	7.0	11.1	18.2			18.2	0.0	18.2	8.0	26.2
Industrial	6.2	10.1	9.7	25.9			25.9	0.0	25.9	4.6	30.5
Transportation	0.0	23.2	1.4	24.6			24.6		24.6	0.0	24.6
Electrical Generation	11.4	7.3	2.6	21.4	14.7	4.8	40.9		40.9	(12.6)	
Synthetics	0.0			0.0			0.0	0.0			
TOTAL	17.7	47.6	24.7	90.0	14.7	4.8	109.6	0.0	109.6	0.0	81.3

Accelerated Supply With Conservation

Household & Commercial	.1	6.4	10.2	16.7			16.7	0.0	16.7	7.0	23.7
Industrial	5.8	9.7	9.4	25.0			25.0	0.0	25.0	4.4	29.3
Transportation	0.0	19.0	1.4	20.4			20.4		20.4	0.0	20.4
Electrical Generation	9.2	6.7	2.7	18.2	14.7	4.8	37.7		37.7	(11.4)	
Synthetics	0.0			0.0			0.0				
TOTAL	15.2	41.3	23.6	80.1	14.7	4.8	99.7	0.0	99.7	0.0	73.4

[1]Source is FEA Project Independence Report. Prices are constant 1973 dollars.

[2]Includes anthracite, bituminous and lignite.

[3]Petroleum products refined and processed from crude oil, including still gas, liquified refinery gas, and natural gas liquids.

TABLE III

U.S. Total Gross Energy Consumption by Major Sources and Consuming Sectors 1985 and 2000. Forecast by the Department of Interior, December 1972.[1] (Quadrillions of BTU's).

Consuming Sector	Coal[2]	Petroleum[3]	Natural Gas	Total Fossil Fuels	Nuclear Power	Hydro Power	Total Gross Energy Inputs	Synthetic Gas Distributed	Total Four Energy Inputs	Utility[4] elec. Distributed	Total Three Sector Inputs
1985											
Household & Commercial	0.1	8.8	10.1	19.0	--	--	19.0	0.9	19.9	7.1	27.0
Industrial	5.2	9.1	13.2	27.5	--	--	28.0	1.1	28.6	5.7	34.3
Transportation	--	25.5	1.6	27.1	--	--	27.1	--	27.1	0.0	27.1
Electrical Generation	14.2	6.7	3.5	24.3	11.8	4.3	40.4	--	40.4	(12.9)	--
Synthetic Gas	2.0	0.7	--	2.7	--	--	2.7	(2.0)	--	--	--
TOTAL	21.5	50.7	28.4	101.0	11.8	4.3	116.6	--	--	--	--
2000											
Household & Commercial	--	11.1	10.8	21,9	--	--	21.9	2.6	24.6	13.7	38.3
Industrial	6.7	14.7	17.9	39,3	--	--	39.3	2.9	42.2	14.2	56.4
Transportation	--	40.0	2.6	42.6	--	--	42.6	--	42.6	0.0	42.7
Electrical Generation	17.5	5.0	2.6	25.2	49.2	6.0	80.4	--	80.4	(28.0)	--
Synthetic Gas	7.1	0.6	--	7.7	--	--	7.7	(5.5)	--	--	--
TOTAL	31.4	71.4	34.0	136.7	49.2	6.0	191.9	--	--	--	--

1 Source is Dupree, W.G. and J.A. West. "United States Energy through the Year 2000." U.S. Department of the Interior. Washington, D.C.: U.S. Government Printing Office (December 1972).

2 Includes anthracite, bituminous, and lignite.

3 Petroleum products refined and processed from crude oil, including still gas, liquefied refinery gas, and natural gas liquids.

4 Adjusted to reflect transmission losses.

scenario), and the effects of combining the conservation and accelerated development scenarios. Each forecast is presented under the assumptions of $7.00 and $11.00 crude oil prices, providing eight conditional forecasts for the years 1977, 1980, and 1985.

The FEA and DOI forecasts have been summarized in Tables II and III on a basis comparable to the ERDA scenarios. In comparing these three government forecasts, we will focus on the comparison of total energy demand, energy demand by primary fuel type, energy demand by major consuming sector, and, finally, the energy demand by fuel type by each major consuming sector.

Comparison of Totals

At the level of aggregate consumption, both the ERDA and FEA post-embargo baseline forecasts for 1985 are substantially below the DOI pre-embargo forecast. The ERDA forecast of 105.7 Quads is bracketed by the FEA forecasts of 102.9 and 109.1 Quads at world oil prices of $11.00 and $7.00 per barrel respectively (1973 constant dollars). This implies that the ERDA forecast corresponds to approximately a $9.00 (1973 constant dollars) world oil price. The aggregate forecasts for the conservation scenarios and the combination of accelerated supplies and conservation are also very close.

The most striking differences occur in the consumption of petroleum. While the ERDA aggregate forecast seems to correspond to a world oil price of $9.00, the 1985 baseline oil consumption estimate corresponds to the FEA $7.00 scenario. Thus the implied import levels seem too high. Interpolating between the two FEA estimates, a $9.00 seems to imply oil imports of approximately 15.7 Quads rather than the 25.9 Quads presently forecast by ERDA. Two factors suggest that even this revised estimate of imports might be too high. First, the FEA analysis has been criticized as underestimating domestic supply and overestimating petroleum demand [5]. Secondly, the assumption of a $9.00 world price of oil may be too low. As a consequence, it appears that ERDA overestimates petroleum demand and therefore demand for imports.

A more complete comparative analysis of the ERDA scenarios will be included in the final version of this paper.

Footnotes

1. ERDA argues that the results of the scenario development and analysis do not represent a forecast of the future. While we accept the inherently conditional nature of the analysis, we find it difficult not to describe these scenario results as forecasts. In Scenario 0, ERDA "forecasts" very high import levels for petroleum under rather explicit assumptions about future supplies of and demands for petroleum. Much of the remainder of the analysis is limited to evaluating how the R,D&D effort would reduce these input levels. Indeed, reduction of inputs is a basic policy goal of the R,D&D effort. If the input levels of Scenario 0 do not represent ERDA's forecast, then it is difficult to interpret their analysis of the success of R,D&D in achieving the national goal of energy independence.

2. The best single reference for the Reference Energy System is [2]. The data presented in that reference bears no direct relation to the ERDA scenario.

3. Note the distinction between end use or final demand by which is meant the demand for BTU's to be delivered as, say, space heat and factor demands which represent the demands against particular technologies to satisfy the final demand. In BESOM final demands are exogenous while factor demands are endogenous.

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