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A Comparative Assessment of Five Long-Run Energy Projections

December 1979

Prepared for
U.S. Department of Energy
Energy Information Administration
Assistant Administrator for Applied Analysis
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December 1979

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ABSTRACT

This report compares five major long-term forecasts prepared under similar assumptions by:

- Professor George Dantzig's PILOT Process Integrated Model/Welfare Equilibrium Model system (PILOT);
- Professor Alan S. Manne's ETA-MACRO energy-economy model system;
- The combined Brookhaven National Laboratory/Dale W. Jorgenson Associates (BNL/DJA) energy-economy model system;
- The FOSSIL2 energy model operated by the Office of Policy and Evaluation in the Department of Energy;
- The Long-range Energy Analysis Package energy model ARC-78 (LEAP), operated by the Energy Information Administration in the Department of Energy.

After summarizing the method of preparation of each forecast, the report compares the results in detail and explains the differences both in terms of data assumptions and methodological approach.

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EXECUTIVE SUMMARY

The Energy Information Administration is required by Congress to present an annual range of energy projections summarizing likely outcomes of alternative energy, economic, and demographic scenarios.

This report compares five long-term projections of the U.S. energy situation for a single common scenario. Recognizing that different authorities have different views of the same situation, this report presents the projections and attempts to uncover the reasons for differences.

The study was coordinated by Brookhaven National Laboratory under the direction of Dr. Andy S. Kydes. The experimental design included preparation of a standardized set of assumptions based upon the ongoing and independent forecasting exercises by the Energy Information Administration and the Policy and Evaluation Offices in the U.S. Department of Energy.

These standardized assumptions were utilized by the other modeling groups to prepare, in all, a total of five projections.

Several major conclusions dominate the comparison of the alternative projections of the evolving U.S. energy and economic systems. There is continued positive growth in total, primary energy consumption despite the continuous escalation of the real prices of primary resources. Though the levels and patterns of growth differ among the projections, there is no evidence of an asymptotic upper limit for primary energy consumption through the first quarter of the next century. From the projections, there is also the implication that liquids constitute both a short- and long-term energy problem for the United States. In the FOSSIL2 and PILOT estimates, oil imports continue to provide a significant fraction of the total liquids demand to the end of their respective time horizons. ETA-MACRO projects the disappearance of imports by 2020 with the increased penetration of a "backstop" technology which is priced competitively with oil and gas imports. As the non-electric backstop is not specifically identified and as it is projected to be a significant component of total primary energy, its presence amplifies the liquids and, perhaps, even the import problem. Only in the BNL/DJA and LEAP projections are oil imports replaced by energy from identifiable domestic resources and technologies. However, the sporadic reappearance of imports in the BNL/DJA projection suggests that the liquids balance between the growth in domestic demand and the growth potential of domestic supply is tenuous. In the context of the future growth, structure, and stability of world oil markets, none of these projections can be viewed as especially comforting.

Another prominent feature of these projections is the predicted role of electricity in the energy system. The models estimate the growth of electricity generation to be in the range of 2.5 to 3.1 percent per annum over the long-run. Although this projected growth is moderate by historical standards, an increasing fraction of total, primary energy consumption is devoted to providing electricity. It is projected that, through 2020, the long-term shift toward the increased centralization of the energy system will slow but will not reverse.

The share of electricity generation provided by nuclear power increases continuously over the time horizons considered for each model. In the pre-2000 period the growth of nuclear power exceeds the growth of total electricity generation with the result that, by 2000, nuclear energy inputs are estimated to account for one-quarter to one-third of total electric inputs. This differential growth continues after 2000 in the FOSSIL2, ETA-MACRO, and LEAP projections. However, in the BNL/DJA post-2000 estimates, nuclear power grows only slightly faster than electric generation, as its allowable penetration was constrained to reflect the pattern of growth for the period 1990 to 2000 in the EIA case specification. Finally, the projections indicate an increased reliance on domestic coal resources for direct combustion, synfuels production, and electric generation. Although the details of coal consumption and conversion vary among the estimates, there are marked similarities in the trends and even the levels of coal consumption provided by the models.

The trends, enumerated above, are sufficiently "robust" among the projections to appear not influenced by the particular, structural representations of the energy and economic systems in each of the models. However, certain fundamental differences exist in the details of these projections which are attributable to differing model structures and which are of major consequence to public policy.

The timing and growth of the synfuel industries differ greatly among the projections. To the year 2005 the estimated trends of market penetration are paired- ETA-MACRO, PILOT, and LEAP versus FOSSIL2 and BNL/DJA. After 2005 ETA-MACRO and LEAP follow a similar path while FOSSIL2 and BNL/DJA form distinct trends. ETA-MACRO and FOSSIL2 project a continuation of the trends established for previous time periods. In the BNL/DJA projection, there are inflection points in the trend line due to the temporal and static energy-economy interactions, as they affect energy demand and supply, and to the market penetration algorithm in the BNL model. Most importantly, the differences in the estimates of synfuels production activity are related directly to the characteristics, both explicit and implicit, of market penetration provided by each methodology.

There is substantial variation in the abilities to incorporate and, hence, estimate the details of energy end-use in the alternative methodologies. Indeed, of the five models chosen for this exercise, three (LEAP, PILOT, BNL/DJA) provide such detail but comparisons of these projections and methodologies are frustrated by differences in accounting conventions and technology characterizations (efficiencies, costs, etc.).

The models differ in the extent knowledge of the future is assumed and employed within each structure and in the interactions (energy-energy and energy-economy) which emerge from the static and dynamic functional relationships contained in each system. Unfortunately, the differences which appear in the projections (e.g., the growth of electric and non-electric energy demands, the energy-GNP ratios, etc.) cannot be linked causally to one of these structural differences in isolation. Rather, it is the structural differences, taken as a set, which provide the explanation for the disparities. It is important to note, however, that much of the predictive power of any methodology is provided by the credibility of the set of assumptions underlying it.

1. INTRODUCTION

Analyses for the ARC of 1977 involved the use of several short-term and mid-range models for sectoral and integrative assessments of energy developments and their economic and environmental consequences. For the long-term analysis, the EIA surveyed the principal energy projections for the years beyond 1990 with special emphasis on the year 2000. The energy projections referenced in the survey were selected because they provided a range of alternative, yet prevailing, long-term views. As these projections were predicated on fundamentally different methodological representations of the energy (energy-economy) system, they embodied and reflected the major uncertainties which characterize the future and, hence, any forecast. Although these projections were internally consistent, there was no common basis upon which to compare alternative long-run forecasts or to relate the long-run views to those for the shorter term.

The analytical efforts for the ARC of 1978 have been designed and organized to permit dynamic and static comparisons among various long-term projections. Specifically, analyses were conducted using five long-run energy or energy-economy system models. These were:

- Stanford University's PILOT Process Integrated Model/Welfare Equilibrium Model system (PILOT or PPIM/WEM);
- Alan S. Manne's ETA-MACRO energy-economy model system;
- The combined Brookhaven National Laboratory/ Dale W. Jorgenson Associates (BNL/DJA) energy model system;
- The FOSSIL2 (1978) energy model operated by the Office of Policy and Evaluation, Department of Energy;
- The Long-range Energy Analysis Package energy model ARC-78 operated by the Energy Information Administration, Department of Energy.

The EIA provided a detailed specification of the underlying economic and energy conditions to be adopted for the ARC assessment. These conditions can be categorized in terms of economic and demographic assumptions, environmental standards, key energy price and price-policy assumptions, and technology characterizations and penetrations. From this specification, the participants selected the minimal subset of assumptions necessary for their models while maintaining consistency with EIA's basic guidelines. The objective was to establish a set of assumptions with sufficient commonality to permit comparison among the alternative projections yet with sufficient discretionary flexibility to insure that the projection was primarily the product of the model sponsor or organization.

Given the nature and magnitudes of the uncertainties intrinsic to any long-run, energy-economy projection, the focus of the EIA in this exercise is the determination of:

- Attainable patterns of future energy supply conversion, and end-use which, in turn, are conditional on the interactions of the assumptions and the alternative structural views of the energy and economic systems;

- The combined influences of the assumptions and the models' structure and content on the results obtained.

This report summarizes the major conclusions of the ARC Support Study. It contains a brief description of each model and elaborates those structural and behavioral features which most significantly influence the nature of each projection. Also presented are the long-term projections from each model. The descriptions and comparisons of the alternative solutions from each of the model systems are reported in terms of the structural aspects of each model and their implications for the real world.

2. ENERGY SYSTEM MODEL DESCRIPTIONS AND FEATURES WHICH INFLUENCE RESULTS

The FOSSIL2 Model System

FOSSIL2, a systems dynamics simulation model, was developed by the Dartmouth Systems Dynamics Group, under Dr. Roger F. Naill, to serve as a simulation tool for evaluating the potential magnitude of the U.S. energy problem and to assess the impacts of various energy policy options on the U.S. energy system. Systems dynamics models integrate three distinct disciplines to analyze social systems:

- Feedback control theory;
- Organizational behavior; and
- Computer simulation technology.

The focus of the methodology applied to energy modeling is the representation of energy flows and decision making as a feedback control system. The idea that social systems (involving human decision making processes) can be modeled with the same techniques as physical systems is the foundation of systems dynamics. Computer simulation techniques provide the means to analyze complex nonlinear systems.

FOSSIL2 [4] is a dynamic, disequilibrium model of the United States' energy system which does not assume that markets always function in an optimal cost minimizing manner. Instead, the model incorporates exogenous decision rules governing the flow of investment, resources, and energy-consuming goods. The model structure represents a causal theory of energy use behavior and is designed to function as a policy tool for analyzing potential energy problems. The model is ideal for a policy environment because in addition to the accounting rules required to track energy flow, the model directly represents the response of corporate, financial, and social institutions to the effects of the evolving energy simulations.

System dynamics models describe activities in terms of three types of variables entitled **levels, rates,** and **auxiliaries.** A **level** is a stock variable representing the quantity of an item such as oil at an instant in time. Levels change with time at a rate specified by **rate variables** . Finally, **auxiliary variables** are those which relate the rate variables to other variables including exogenous variables. Mathematically, FOSSIL2 corresponds to a set of difference equations in which the levels are the state variables whose time rate of change is defined by the rate and auxiliary variables.

Using difference equations to represent the state determined dynamics of the system has an important implication relating to the theory of general economic equilibrium: the value of a level variable in a given time period can depend only upon values of level variables from previous and current time periods. This "state-determined" nature of systems dynamics models differs from the situation in general equilibrium models whose mathematical structures permit optimization over current and future time.

The FOSSIL2 model dynamically simulates the behavior of the energy system from 1950 through 2020, projecting gross and net production, fuel-specific demands, and prices. It portrays the growth in U.S. energy production and consumption (1950-1980), the peak and decline in domestic oil and gas production (1970-1980), and the transition away from rapidly depleting oil and gas to alternative energy sources (1980-2020). It is in this transition period that the U.S. faces the greatest problems of balancing total energy supply and demand. FOSSIL2 was developed as a tool to aid policymakers in assessing the outcome of different policy options on the U.S. energy system during the transition period and, thus, serves as a guide in designing a sound, unified, long-term energy strategy.

Structure of FOSSIL2

The future direction of the energy system is determined largely through the interaction of energy producers and consumers in markets. Government policies can also affect the system by changing the market mechanism of energy supply and demand. FOSSIL2 captures both the decision-making processes of producers, consumers, and major government policy levers within its structures.

Figure 1 shows the basic interactions between energy producers and consumers included in FOSSIL2. Energy consumers continually make decisions each year to utilize oil, gas, coal, or electricity based on both the price and availability of the fuels. Energy producers, in turn, choose to invest in the product that maximizes the industry rate of return (or minimizes the average cost of production), subject to various constraints (e.g., environmental restrictions) and government policy.

Both end-use consumption decisions and producers' investment decisions accumulate through time to determine the net

INTERACTIONS BETWEEN ENERGY PRODUCERS AND CONSUMERS

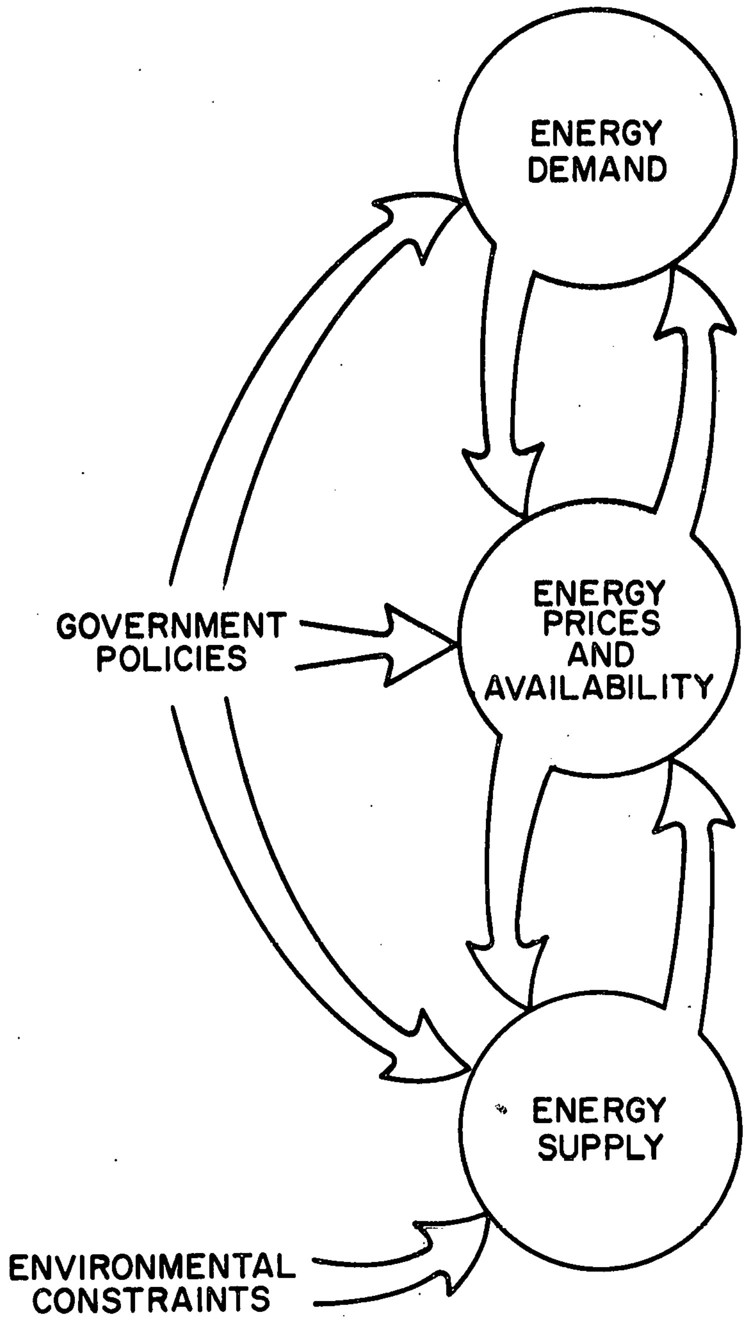


Figure 1

demand and production capacity for each fuel. If an imbalance develops between demand and capacity, energy prices will then adjust through market forces to restore the balance (in the absence of price regulation).

FOSSIL2 does not assume instantaneous adjustment of energy supplies and demands. It explicity represents the adjustment lags caused by the need to turn over energy producing and consuming capital stocks. Thus, for example, a sudden rise in the price of imported oil does not result in a sudden reduction in imports because energy producers need time to develop alternative sources, build plants, and begin producing more energy. Likewise, energy demand does not respond immediately to rising prices because the demand for energy depends on capital stocks (goods which use energy) which cannot be abandoned at acceptable costs nor immediately change to require less energy or different energy forms.

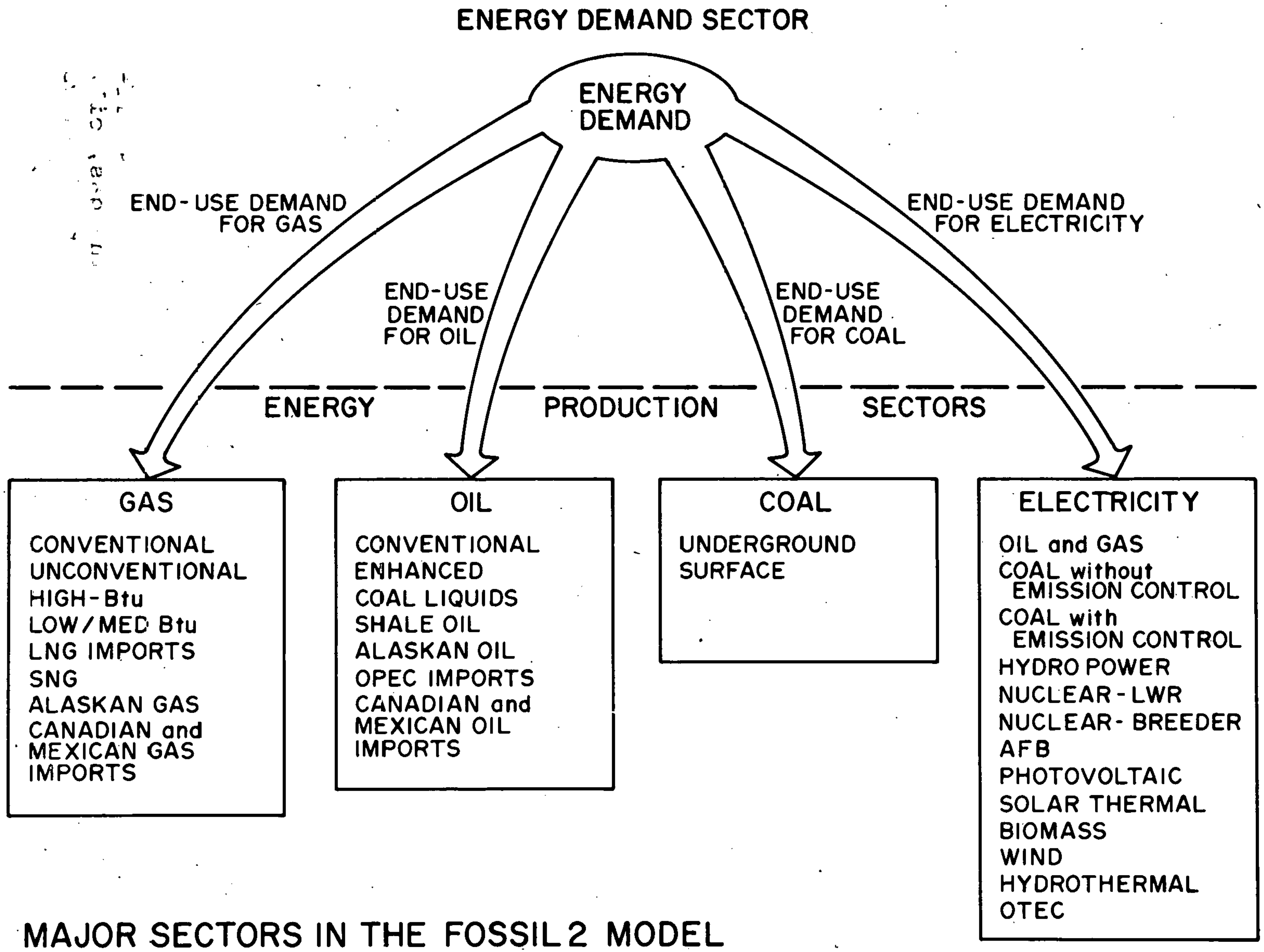
Supply

In FOSSIL2 the energy system is divided into five sectors (Figure 2): a demand sector and four production sectors (oil, gas, coal, and electricity). Each of the production sectors is further subdivided into supply/demand balance, financing, and production subsectors.

Given fuel-specific demands, the four production sectors try to meet the demands so as to maximize profits (or, identically, by minimizing costs). As the demand for energy "flows" into a sector, the sector adjusts both its production rate (within the constraints of its production capacity) and its price to try to meet that demand (supply/demand subsector).

Over the long term, each sector adjusts its production capacity to meet demand through investments in new facilities and technologies (financing subsector). However, the production sectors face several constraints in developing new capacity, including the availability of funds and construction lags. In addition, environmental constraints and regulatory policies can limit investment and prevent an industry from reaching an optimal production capacity and mix of technologies.

Within each sector there is more than one way of producing the form of energy needed to meet the fuel-specific demand (production subsector). Oil can be produced from conventional wells, shale oil, coal liquids, or by enhanced recovery methods. The electricity sector can use up to 14 different processes to produce electricity, including gas, oil, coal, nuclear, and renewable resources. Figure 2 shows the full range of energy supply technologies included in FOSSIL2. As energy is produced and non-renewable resources are developed, FOSSIL2 assumes that the least expensive,



MAJOR SECTORS IN THE FOSSIL 2 MODEL

Figure 2

most easily-obtained portions or the resource base are consumed first, leaving the more costly portions for future use. The model allocates investment among the alternative production processes based on the relative costs of each technology.

Demand

The 1978 version of FOSSIL2 gives a highly aggregated treatment of energy demand. The demand sector calculates the total end-use demand for energy in the U.S., based on the movement of the gross national product (GNP) and the average energy price. End-use demand is then broken down into demand for several specific forms of energy--gas, oil, coal, electricity, and decentralized energy.

Interfuel substitution is modeled explicitly and is influenced by the availability (e.g., gas curtailments) and the convenience of the four fuels--oil, gas, coal, and electricity. In addition, sector-specific differences in delivered fuel prices feed back to influence the interfuel substitution possibilities. This demand structure limits the model's utility for energy demand analyses in a number of ways:

- Demand is not broken down into transportation, commercial, residential, and industrial energy usage categories. The net effect of sectoral end-use detail is partially captured in FOSSIL2 through the use of saturation points for fuel substitution.

- Though energy prices do feed back to affect GNP and energy demand/GNP, the underlying growth of the U.S. economy is exogenous to the model.

- The model can account for technological details such as end-use device costs and end-use conversion efficiencies only by external analysis.

- FOSSIL2 is a national energy model and, therefore, regional energy policies are, with few exceptions, not testable.

The energy production sectors also demand energy from each other. Since electricity converts gas, oil, and coal (as well as other energy sources) to electrical energy, the electricity sector must demand feedstocks from those three production sectors. Similarly, synthetic gas and oil are produced from coal and, therefore, the oil and gas sectors will demand coal once synthetic conversion plants have been constructed in the model. Figure 3 shows the composition of total demand for each fuel form.

In summary, FOSSIL2 is, essentially, a supply model which provides a representation of energy flow from extraction to delivered end-product, including synthetic and electrical conversion. FOSSIL2's structure includes modeling mechanisms that allow for the explicit representation of oil and gas depletion, delays in market response, regulation, and exogenous shocks to the energy system. Because it is easy to use, it is accessible, and it can handle a number of different types of policy options, FOSSIL2 is very useful as a first-pass indicator of system behavior under varying conditions.

COMPOSITION OF ENERGY DEMAND IN FOSSIL 2

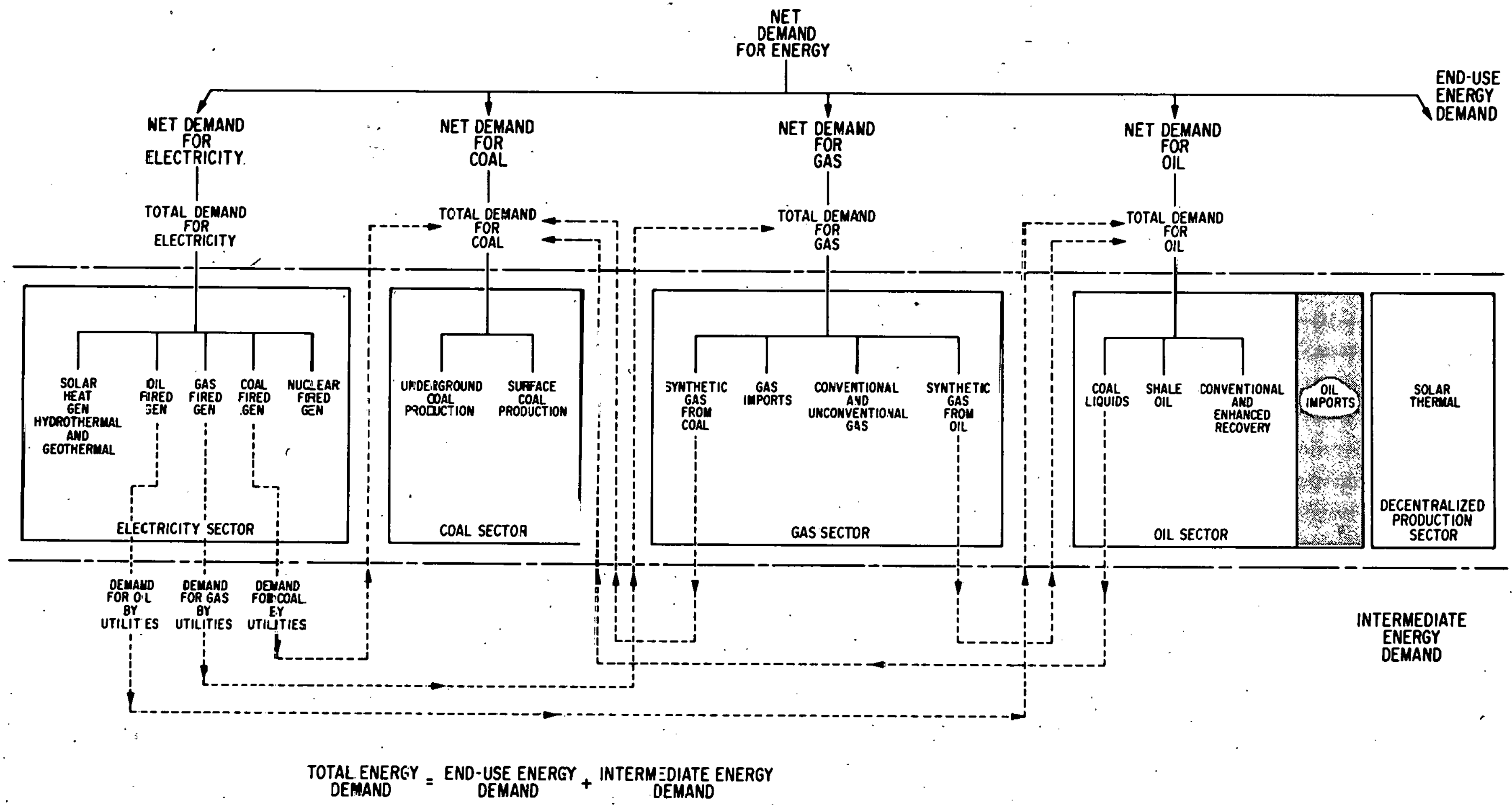


Figure 3

The PILOT Model System

The PILOT energy model system, initiated by Professor George Dantzig at Stanford University's System Optimization Laboratory in 1975, presently houses several energy models. Of these, two dynamic energy/economic growth models, PPIM and WEM, were used jointly in this study. The EIA scenario assumptions were fed to WEM, an economic growth model containing a process submodel of energy supply and a variable coefficient input/ouput industrial system, which is driven by a household welfare function of consumption and leisure time. WEM produced a dynamic, economic equilibrium solution. The labor, capital, energy input/output coefficients of the non-consumer sectors, and the workweek hours, all in time profile indices form, together with the EIA scenario assumptions, were next fed to PPIM. PPIM is also an economic growth model, with a fixed coefficient input/output industrial system. However, it contains a more detailed process submodel of energy supply than WEM and yields a detailed physical flow solution. The shadow prices of WEM, the energy supply/demand balances, and the macroeconomic variables of PPIM are reported as the model solution.

Structure of the PILOT Process Integrated Model (PPIM)

PPIM [2], [5], [12], is an input/output, dynamic, economic growth model linked with detailed, process type submodels of energy extraction, conversion, and supply and of residential and automobile energy services consumption. PPIM is a tool for assessing long-term energy/economic options of the U.S. and for evaluating new energy production and conservation technologies. The input information required for the model can be grouped into six categories:

- Population, labor force, and labor productivity projections;
- Projected non-energy sectors input/output coefficients;
- Resource bases for oil, natural gas, uranium, and eastern and western coal in quantities and extraction costs;
- Energy import prices;
- Costs and efficiencies of energy conversion and delivery systems;

- Upper bounds to represent environmental, technological, and penetration restrictions on growth of energy technologies.

PPIM is a time-phased, linear programming model of a single region which optimizes over a planning horizons of up to 100 years, beginning in 1973. The planning horizon must be partitioned into integer multiples of five years. Given population, workforce, and labor productivity projections, the model calculates the projected economic growth which maximizes a linear objective function. Usually, the objective function used is the discounted sum of personal consumption over the time horizon of the scenario run. Economic activity is represented by sectors: twelve producing, seven non-energy, and five energy. The energy sectors are modeled through a detailed description of raw energy extraction and conversion processes including exhaustible and renewable resources and existing and new technologies. The inputs for producing the non-energy sectors are characterized by fixed input-output coefficients, including labor and non-competitive imports. These coefficients for each of the time periods must be provided exogenously. The GNP of each period is divided endogenously between capital formation, for replacing retired capacity, capacity expansion, and consumption that provides the nation's current standard of living. Imports cannot exceed the available revenue from exports in any five-year period. Consumer's demands for goods and services including energy services are described by linear functions of population and personal income. The ability of consumers to select residential, end-use energy systems of different types and efficiencies, to insulate homes, and to select different automobile prototypes is modeled through the process-type, consumers end-use submodel. Figure 4 shows a schematic description of the linkages within PPIM.

<u>Output Variables</u>

Economic output data includes the macroeconomic aggregates of consumption, capital formation, government expenditures, imports, exports as well as industrial production and factor returns.

Energy outputs include: oil and gas drilling; reserve additions and production; eastern and western coal production and transportation; uranium mining and milling and stocks of nuclear materials; new, energy technologies introduction and output levels; electricity production by type of power plant; fuels used by type of conversion process; fuels consumption by each sector of the economy; energy imports and

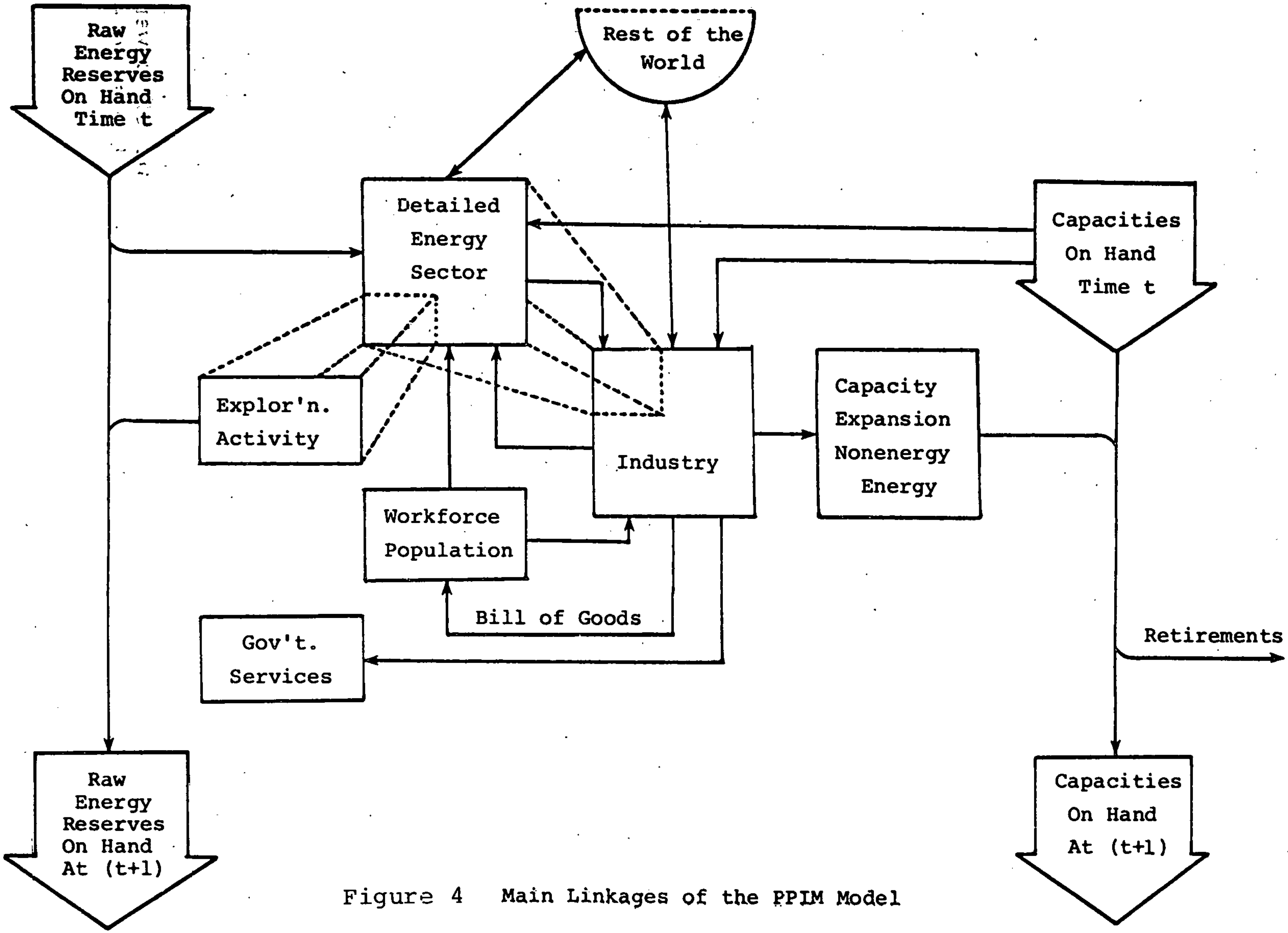


Figure 4 Main Linkages of the PPIM Model

exports; existing and new capital stocks of all energy extraction; conversion and delivery systems and their utilization factors; electrification; coal use in utilities, industry, and synthetic fuel production; residential, transportation, and industrial energy consumption by sector and type of fuel; cumulative and added capital stocks of residential end-use energy stocks and automobiles; new homes insulation levels; fuels consumption by type of residential, end-use energy system and energy service; automobile fuel consumption and efficiency levels.

Figure 5 is a schematic flow chart of the energy extraction, conversion, and supply submodel of PPIM. It indicates the areas where technical coefficients are defined, e.g., exploration and production of oil and gas, extraction of uranium, and of other energy technologies.

The inelasticity of consumer's, energy service demands and the exogenously determined industrial, input/output coefficients are oversimplifications. The integrated, process type representation of energy supply and consumer fuel demands provides a rich detail in an overall unified framework. The link with the Welfare Equilibrium Model (WEM) enables PPIM to compensate for the otherwise fixed, industrial input/output coefficients and to reflect industrial interfuel substitution and cost-effective conservation.

The Structure of the PILOT Welfare Equilibrium Model (WEM)

WEM [13] is a time-phased (farsighted), single region linear programming model (approximately 700 constraints and 3000 variables) for developing internally consistent, long-run projections of energy supply, demand, and economic growth within an economic framework of aggregate, consumer welfare maximization. Economic welfare is assumed to be a function of per capita consumption, average workweek, and population. Substitution across labor, capital, and energy permit the economic system to adjust to energy scarcities.

Dynamics

The model explicitly incorporates the dynamics of consumption investment decisions and pricing strategies for exhaustible resources. The discount rate for household welfare works through the consumer demands to other capital formation demands. The capital stock addition decisions are thus made on the basis of the discount rate imputed through this mechanism. Long-run, marginal, cost curves are used for specifying the domestic resource availability.

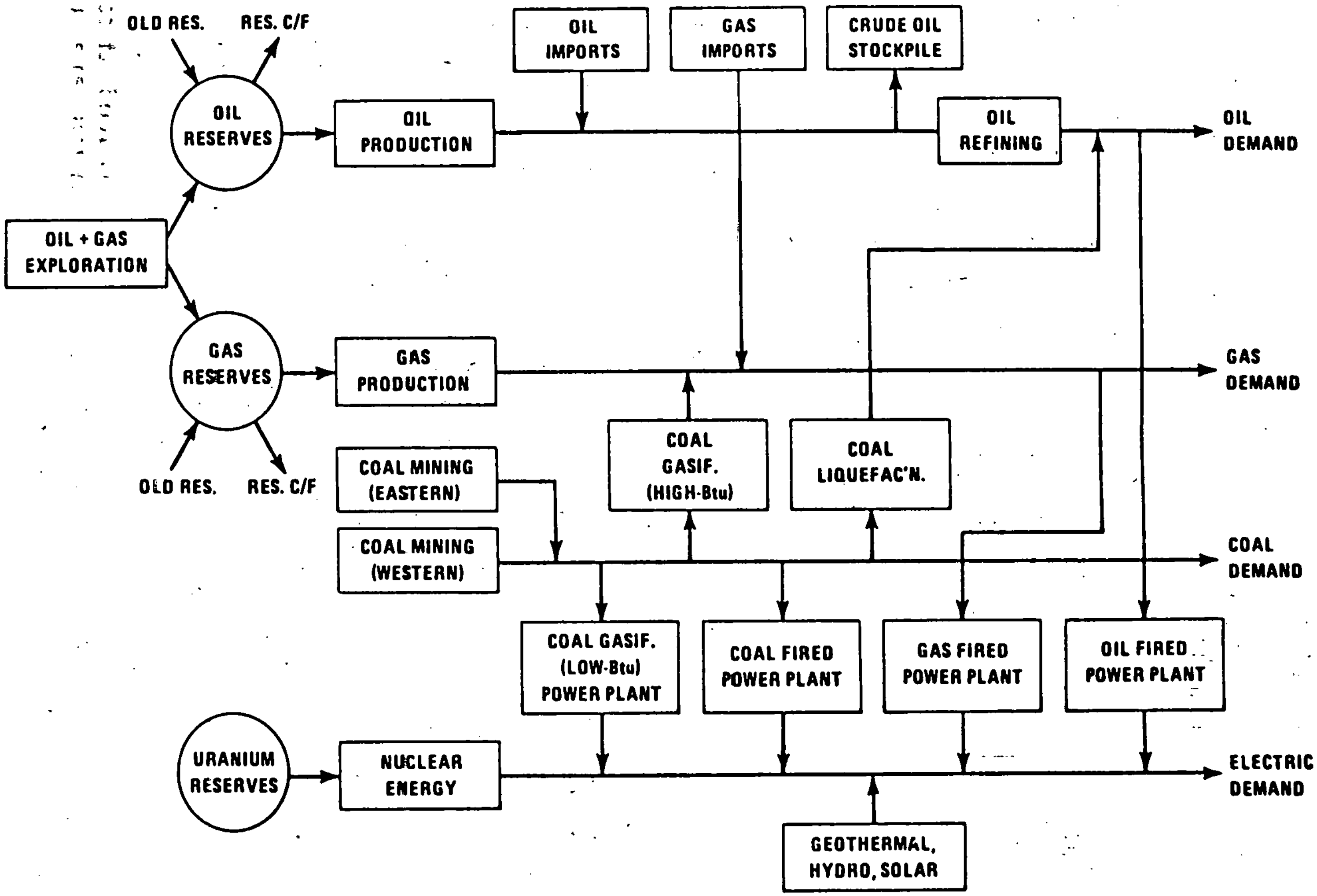


Figure 5 PILOT ENERGY SECTOR

Industrial Production (Non-energy)

The seven non-energy industrial sector projection processes are described through hierarchical production functions: sector-specific, labor/capital substitution uses a constant elasticity of substitution (CES) specification; sector-specific, energy/value added substitution is modeled using a similar formulation. Industrial energy is decomposed into industry-wide substitutable energy and sector-specific non-substitutable (complementary) energy. The latter is intended to specify the raw material and other non-substitutable energy requirements and, therefore, is proportional to the output level of an industrial sector. The substitutable industrial energy is provided through a mix of coal, oil, gas, and electricity and is modeled through CES functions that describe the possible shifts across the following pairs of fuels: electric/non-electric, coal/oil-gas, and oil/gas.

Labor-Leisure Choice

The historical trends are consistent with the behavior that, as the per capita consumption level rises, the length of the average workweek declines. The tendency for this trend to continue is reflected by a household welfare function that describes the so-called labor-leisure choice. This choice reflects the diminishing marginal utility of consumption at a given level of leisure. The marginal utilities of consumption and leisure are positive.

The household, welfare function is a function of four time profiles: per capita consumption (endogenous), average workweek (endogenous), population (exogenous), and discount factor (exogenous). This function is first defined in per capita terms, then weighted by population and discount factors for each period and summed over time. Two key parameters that enter the specification of the household welfare function in per capita terms are the reference potential workweek and the elasticity of substitution between per capita consumption and leisure time. The reference potential workweek is assumed to be 48 hours. Per capita, weekly leisure time is defined as a product of:

- The difference between the reference potential workweek and the average workweek; and
- The exogenous participation rate of the employed workforce.

A specification of constant electricity of substitution between per capita consumption and leisure time is used, and the elasticity of substitution is obtained through trend analysis of historical data for per capita consumption, average workweek, and wage rate.

Foreign Trade

Import-export activities are explicitly modeled. In particular, oil and gas import activities are included. The trade, balance constraint requires matching exports to pay for the imports. The model can also be used to evaluate tariffs/subsidies designed to control trade to meet national goals. The trade, balance constraint appears critical in determining the level of imports and, hence, the attractiveness of advanced technologies on a purely non-energy cost basis.

One key assumption (constraint) plays a potentially crucial role in the WEM results: energy imports are restricted to an exogenously specified percentage of total, domestic resource consumption. The PPIM modelers feel, however, that this assumption does not seriously affect the integrated results of the PILOT system since the PPIM does not restrict energy imports. The balance of trade requirement of PPIM plays an important role in the results of the PILOT system.

Energy-Economy Interactions in WEM

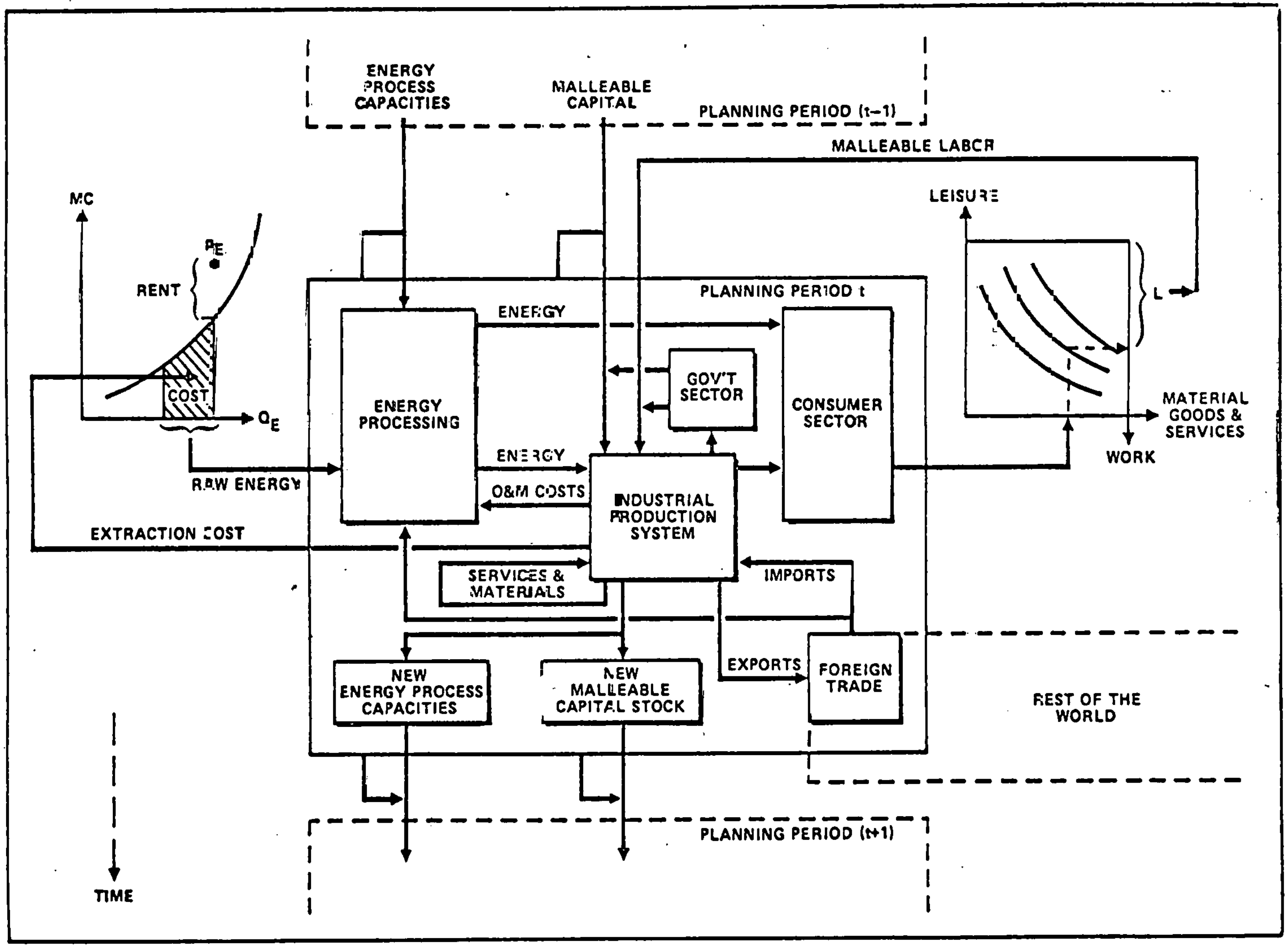


Figure 6

The ETA-MACRO Model System

The ETA-MACRO [10] model, developed by Alan Manne of Stanford University to study the interrelationships between U.S. economic growth, conservation, and energy technologies is a normative optimization model. Constraints regarding energy demand, supplies from existing and new technologies, and factors associated with development of supply technologies are incorporated.

Structure of the Model

ETA-MACRO represents a merger of a process analysis model for Energy Technology Assessment (ETA) with a macroeconomic growth model which captures substitution possibilities between capital, labor, and energy inputs (MACRO). The ETA model is linked to the MACRO model through the equilibrium price and quantity of energy in the domestic economy. This system is a tool for integrating long-term energy supply and demand projections. It is designed to compare the options that are available to the U.S. as the country moves away from its present heavy dependence upon oil and gas resources toward a more diversified, future energy economy.

In order to account for the eventual exhaustion of today's fuels, the time horizon is divided into 16, five-year time intervals extending from 1975 through 2050. This is a dynamic model. It assumes that producers and consumers are sufficiently farsighted to anticipate the scarcities of energy likely to develop during the 21st century.

ETA-MACRO allows explicitly for:

- Energy-economy interactions--the prospect that rising energy costs and limited supplies will prevent the economy from achieving its full potential GNP growth rate and that this effect, in turn, will slow down future, capital accumulation;
- Cost-effective conservation--the reduction of energy demands below the amounts projected from historical trends;
- Interfuel substitution--changing conditions inducing consumers to replace oil and gas with electricity, e.g., heat pumps in place of fuel burners; and

- New supply technologies--synfuels, nuclear and solar power, each with its own difficulties and uncertainties on cost dates, and rates of introduction.

All numerical, input data can be organized into six categories as follows:

- Macroeconomic parameters--the **potential,** GNP growth rate at constant energy prices, the elasticity of aggregate, energy demand subsitution, and "value shares" for the nested production function;

- Upper bounds (if any) to represent environmental restrictions upon total coal consumption;

- Cumulative supply curves--quantity versus marginal selling price (replacement cost) for oil, gas,

- Introduction limits (if any) and input/output coefficients for each supply technology;

- Technology groups for the standard ETA--MACRO report.

The output data consists of: domestic energy consumption (by source), petroleum and gas imports, total energy consumption, electricity generation (by source), cumulative resource requirements, nuclear fuel requirements, energy prices, GNP, present value of consumption at a 5 percent and 10 percent discount rate, annual investment rates for electric utilities, and production capacity levels for all technologies.

Energy **prices** are derived from the dual variables of the non-linear programming algorithm. Hence, they measure marginal replacement costs rather than actual average market prices.

Oil, gas, and coal are aggregated into a single category: "non-electric energy." Electricity is described in terms of total kilowatt hours. The load-duration curve is not modeled explicitly, but a provision is available to approximate the advantages of fossil-fired units for intermediate and peaking duty. This classification system is highly aggregated. More detailed characterizations would be needed to analyze specific proposals for energy conservation or specific projects for the expansion of production capacity.

The demand for energy in ETA-MACRO is derived through an aggregate, production function. This production function is in nested form to minimize the number of parameters that need to be estimated from time series or cross-section data. It then becomes an easy matter to perform sensitivity analyses on demand elasticities. Alternative values of the aggregate elasticity of energy demand substitution (ESUB) can generate substantial differences in energy demand. This parameter is crucial for understanding the extent to which energy consumption and economic growth may be uncoupled from each other.

The economy uses energy in two basic forms: electric and non-electric. The gross output of the economy, expressed in GNP terms, depends upon the inputs of energy, labor, and capital. In turn, the output is allocated between current consumption, investment in building the stock of capital, and current payments for energy costs. The macroeconomic production function in MACRO provides substitution among the factor inputs--capital, labor, and energy. The response of the economy to energy, price increases and supply shortages is to initially substitute labor and capital for energy. These tradeoff possibilities are captured by the elasticity of substitution (ESUB) parameter in the production function (see Figure 7.)

In the ETA model, estimates of the demand for energy are determined through a hybrid of econometric and engineering, process, analysis techniques. The energy, demand functions provide for substitutability between energy and other economic inputs. The ease or difficulty of such tradeoffs is summarized through the ESUB parameter. The allocation of demand between the two forms of energy, i.e., the market share, is accomplished by using individual price elasticities.

The supply side of ETA is handled through a conventional linear programming process analysis. Electric energy can be produced by coal-fired powerplants, light-water reactors, and advanced electric technologies (e.g., solar, fusion, or an advanced breeder). Non-electric energy (liquids, gases, or solids) may be supplied by oil, natural gas, coal, shale-based synthetic fuels, or hydrogen via electrolysis. The depiction of these sources of energy is performed through a price-quantity schedule for each future year, reflecting capital and associated costs involved in extraction/generation/conversion of the final form of energy.

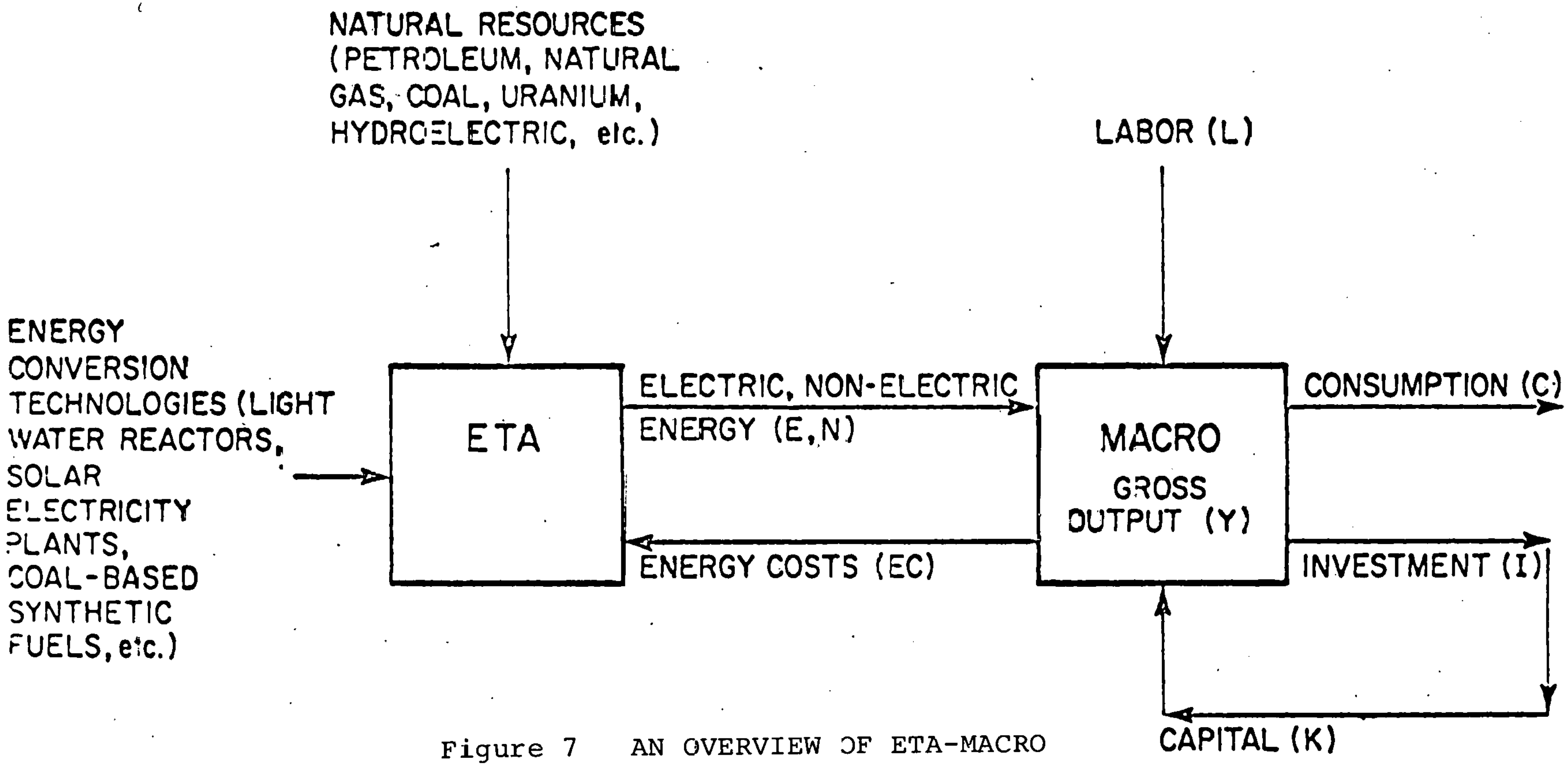


Figure 7 AN OVERVIEW OF ETA-MACRO

An intertemporal market equilibrium for the energy sector is approximated by optimizing for the minimum of the sum of conservation, interfuel substitution, and energy supply costs. The objective function, which is non-linear, treats the costs and benefits in present dollars by using a 75-year planning horizon and a social discount rate. Except for the use of the higher discount rate, which reflects uncertainty about the future, the optimization is in a deterministic framework.

Trends in the labor force, productivity growth index provide the principal driving force for the potential GNP and, hence, the expansion of energy demands over time. Demand growth in the two sectors, electric and non-electric, is expressed as a function of the annual rate of GNP growth, own and cross-price elasticities (exogenously determined), and the annual rates of own-price increase and competing, fuel price increase (endogenously determined). A unitary elasticity of substitution for electric and non-electric energy demand is assumed; however, the equilibrium, electric energy demand has an upper bound, expressed as a fixed value share of total primary energy.

Typical key input assumptions for the ETA-MACRO runs include: price-quantity schedules for the energy supply sources, elasticities of substitution labor and capital for energy, potential GNP growth rates, and delivered energy costs for various technologies (e.g., electric or synfuel options). Although there are many more assumptions within the framework of the model, these appear to be the most important in determining the results.

The BNL/DJA Model System

The combined, BNL/DJA, energy-economy model system consists of a coupling of an economic growth model, the Hudson-Jorgenson Long-term Interindustry Transactions Model (HJ/LITM) [6,7] available from Dale W. Jorgenson Associates (DJA), with an energy model, Brookhaven National Laboratory's Time-stepped Energy System Optimization Model (TESOM) [8]. The coupling is accomplished through an integrative interface which is essentially a "reduced-form" version of the Brookhaven/University of Illinois Input-Output Linear Programming Model [9].

The DJA model, also known as the Hudson-Jorgenson Long-term Interindustries Transactions Model (LITM), is a simulation model of the structure and growth of the U.S. economy. It combines a two-sector (consumption, investment) and two-factor (capital, labor) neoclassical model of macroeconomic growth with a multi-sector, input-output model using flexible coefficients. For each year, it analyzes economic activity on a sectoral basis and integrates these sectors into a consistent whole. There are ten producing sectors: four are non-energy and six energy. These sectors, in turn, consist of energy extraction and processing activities. These sectors are:

- Agriculture, non-fuel mining, construction;
- Manufacturing;
- Transportation;
- Services, trade, communications;
- Coal mining;
- Crude petroleum;
- Petroleum refining;
- Electric utilities;
- Gas extraction; and
- Gas utilities.

In addition, there are three other sources of inputs into production (capital, labor, and competitive imports) and four categories of final demand for goods and services (personal consumption expenditures, investment, government purchases, and exports). These activities are organized into a matrix of interindustry transactions with thirteen supply sectors and fourteen purchasing sectors. Within this interindustry framework, balance or consistency is required to hold.

- First, price formation must be sufficient for sectoral output prices to cover average costs of production including a normal rate of return.

- Second, quantities must be such that, for every sector, the output of a sector exactly matches the quantity of that good or service required for input into other producing sectors, together with the quantity used to satisfy final demand.

- Third, prices and quantities must be such that the revenue received by a sector is exactly accounted for by payments to inputs, including income to capital, and by payments to governments.

- Fourth, the demands for capital and labor inputs must be consistent with the supplies of these resources.

- In addition, imports are constrained by the available revenue from exports together with a limited foreign deficit.

Activity patterns within this framework are represented by econometric models. The submodels for consumption and for each of the producing sectors incorporate the patterns of behavioral and technical responses observed for these activities. This approach gives a flexible and consistent representation of economic behavior. These submodels provide a framework for the analysis of output price formation and, with the above consistency conditions, determine the system of relative prices characterizing the economy. Also, these submodels determine the particular pattern of input purchases (the input-output coefficients) that, of all feasible input patterns, represents the cost minimizing pattern given prevailing prices. This means that the input-output coefficients are endogenous, being functions of, **inter alia**, relative prices. Similarly, the pattern of consumption spending is modeled in a flexible manner. These features provide for the incorporation of the substitution or complementarity relationships between inputs and the adjustments in the pattern of consumer expenditure. As a result, some of the principal adjustment mechanisms in the economic system are explicitly incorporated in the model.

The DJA model is a dynamic equilibrium model of the U.S. economy. For each of the endogenous commodities in the model, an algorithm determines relative prices based on the balance between demand and supply. Equivalently, the pattern of economic activity in each year is consistent with prices as determined by the observed patterns of substitution and other responses by producers and consumers. In addition, the model includes a balance between saving and investment that determines the rate of return and the rate of growth of capital stock. Economic growth is modeled as a sequence of one-period equilibria determining demand and supply and relative prices for all commodities. Investment in each period determines the level of capital stock available in the following period. Dynamic adjustment to energy changes is modeled by tracing through the impact on future levels of capital stock and the rates of change of factor productivities.

The BNL model, TESOM, is a national, energy system model based on Brookhaven's Reference Energy System (RES). The RES provides a complete and consistent accounting system, in physical units, for energy flows through energy technologies (stocks). With appropriate conversion efficiencies, the RES proceeds from the extraction or importation of primary energy resources and products, through refining and the various stages of energy conversion, transportation distribution, and storage, to the consumption of fuels and electricity by end-use technologies corresponding to a particular, energy service demand. Within the RES, emphasis is placed on a comprehensive technological structure relating energy flows which enter the system (oil, gas, coal, uranium, solar, etc.) to the relatively nonsubstitutable, functional, energy services that are the final product of the flow (space conditioning, motive power, process heat, lighting, etc.). Thus, the RES framework reflects the full, feasible range of interfuel and technological substitutability.

For each year the model optimally allocates energy resources and products and selects the optimal mix of supply, conversion, and demand technologies according to least-cost economic criteria to satisfy a specified set of energy service demands. Resource supply representations are specified as long- or short-term supply curves or fixed prices and availabilities by year. The TESOM model provides a "vintage" representation of the nation's energy system in that the optimal levels of the decision variables for any time-period are determined from:

- The optimal levels established for previous periods;
- The retirement and deterioration rates, the lifetimes, and the associated costs of vintage capital stocks; and
- The economic and technological factors affecting the feasible levels of the decision variables for the period under investigation (e.g., decline rates, supply elasticities, cumulative resource availabilities, market penetration considerations, etc.)

Mathematically, the model is formulated as a sequence of expanding, linear, programming formulations of the RES--one for each time period. For a given time period, the solutions derived for earlier periods are incorporated into the sequenced formulation along with assumptions regarding retirement and decline rates, average lifetimes, age-dependent conversion efficiencies, plant factors, O&M costs, and the capital charges for the stocks-in-place. Then, at least--cost or other quantifiable criteria, the energy demands are satisfied in accordance with the supply expansions and increased penetrations that are attainable for the period and the net availabilities from the evolution of the energy system to date. In meeting future energy demands, TESOM has a memory of the net availabilities from the past, augmented by availibilities attainable in the near-term. The updating and sequencing procedures are repeated until solutions for the entire time horizon are determined.

TESOM provides a detailed representation of the electric sector. A set of **demand types** (e.g., base and intermediate loads, off-peak, heating, cooling, etc.) are defined. Each demand type has its own set of characteristics regarding its stochastic behavior and its seasonal (winter, summer, spring-fall) and daily (day, night) loading. Required capacity is governed by the highest, total peak demand which occurs during some time of the year and day. By appropriately loading the electric energy service demands onto the various (or, in some cases, corresponding) demand types and, subsequently, loading these demands onto the various season-day combinations, the height of the total peak for each season-day is determined. Required capacity is simply the maximum of the individual season-day peaks with allowances for transmission and distribution losses and reserve margins. This feature permits the introduction of load management considerations into the problem formulation as the load duration curve is, in part, exogenously determined from the detailed demand characteristics and their implications for the electric system.

TESOM also contains a number of features designed to smooth the intertemporal transitions indicated by the sequence of solutions. Among these are the mechanisms for pricing and adjusting the availabilities of vintage stocks and an improved, market penetration algorithm which avoids the "bang-bang" characteristic of linear programming models. To the extent that the age of a vintage stock is not beyond its economic lifetime, the annualized capital charges for the technology impose a cost on the system. Thus the fixed costs associated with previous investments are incurred irrespective of whether or not it is optimal to operate, partially or fully, an older technology. "Unrealistic" displacements of relatively inefficient vintages are discouraged when the associated variable costs of alternative stocks are combined with the fact that immediate write-offs are precluded.

The procedure for market penetration requires, as input, "optimistic" penetration levels for each technology in each year. The penetration algorithm then incorporates the marginal values, implementation rates, and lag times from previous periods as well as the technological and market characteristics for the current period into the determination of more realistic bounds for the activity levels. The user-specified bounds are adjusted endogenously to account for the previous penetration and attractiveness of the technology.

An overview of the BNL/DJA combined modeling system is presented in Figure 8.

For a given analysis, it is necessary to incorporate the assumptions appropriate to each of the components into the energy and economic system models. For the energy model, these assumptions include: energy technology characterizations (costs, load, and plant factors, conversion efficiencies, backup requirements, capacity limitations, etc.); environmental emission relations, and energy supply relations (prices, costs, availabilities, quotas, etc.). For the economic model, these assumptions include: a population projection; government tax policy and expenditures; other exogenous, final demand purchases; the unemployment rate, etc.

Having aligned the combined model system to the input assumptions, the integration-solution procedure is initialized as follows. Average supply price indices for the projection are estimated using, as weights, the energy quantities from a previous BNL/DJA reference projection. The price changes

BNL/DJA COMBINED MODEL SYSTEM

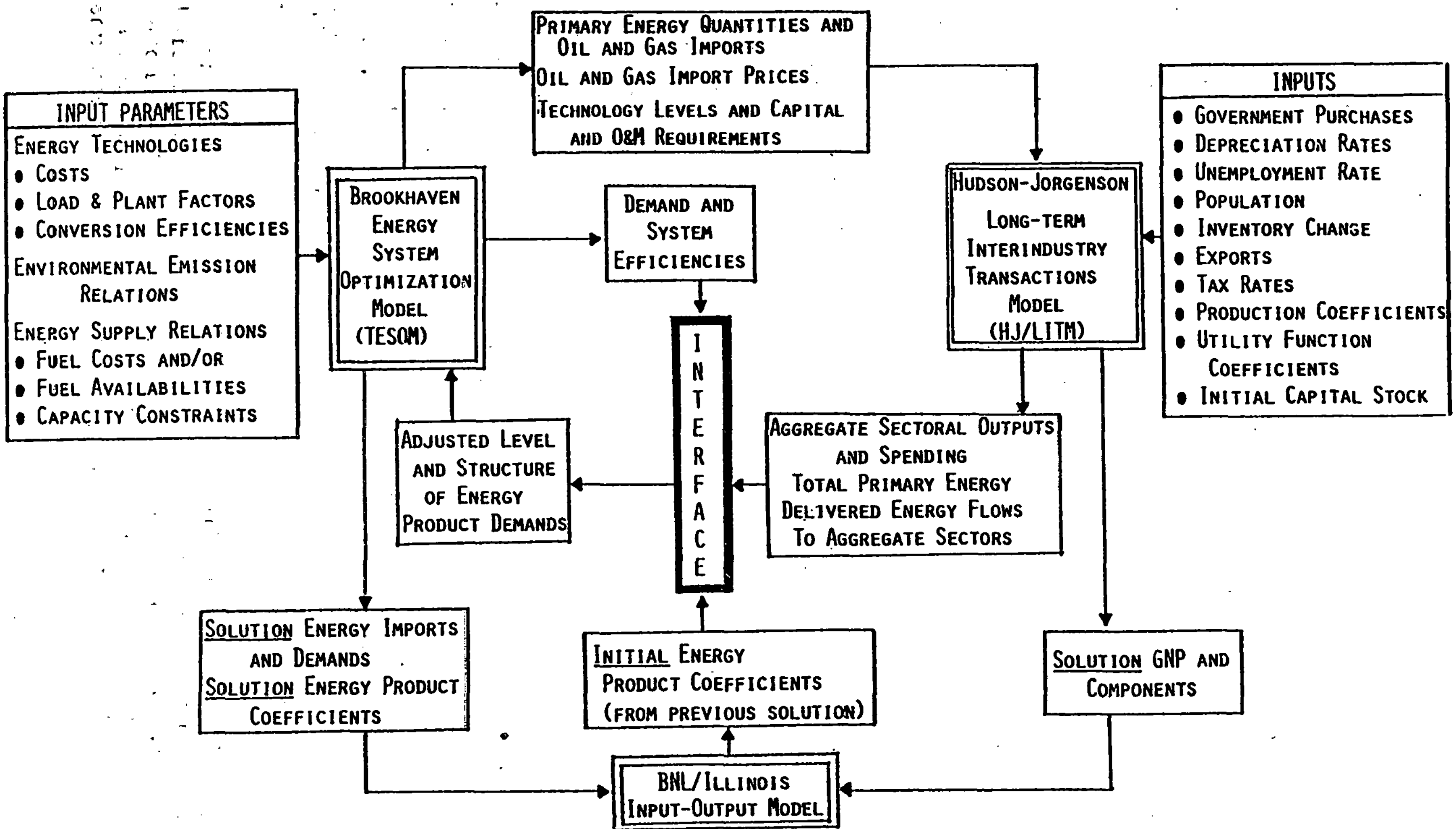


Figure 8

from the reference projection are related to price-quantity elasticities of demand to yield the initial estimates of primary energy consumption and, through average system efficiencies, the corresponding, energy service demand levels. These elasticities summarize the equilibrated degree of responsiveness of energy quantity changes to energy price changes from previous solutions of the combined system. TESOM is then solved, constrained by the supply and conversion limitations and subject to the satisfaction of these initially determined levels of energy services.

The solution values of energy prices, capital requirements, quantities, imports, and the levels of new energy technologies are entered into the DJA model, which is solved to yield specific estimates of the level and composition of production and spending throughout the economy. Economic sector activities and the energy input per unit of economic activity are transformed into a restructured set of demands for energy services in physical units. This mapping occurs through a "reduced-form" version of the BNL/University of Illinois Input-Output Model. Mathematically, these adjustments to the level and structure of the service demands are determined by account for:

- Changes in the service levels due to changes in the level and composition of economic activity; and

- Changes in the service levels due to the changes in the energy input (expenditure) per dollar of output (final demand spending for each producing (consuming) sector. This change accounts for the substitution of non-energy inputs in production and consumption.

The final adjustment in the mapping process accounts for changes in the demand levels provided by the efficiency improvements (from the previous TESOM solution) in each service category. At this point, the energy demand vector reflects changes in energy prices, the level and composition of economic activity, energy and non-energy input substitutions in production, and the component system efficiencies. These energy demands are inserted into TESOM and produce a new simulation of the configuration of the energy system. This iterative process continues until consistency between the energy and economic systems in the two models is attained. The details of the interface procedure are presented in Figure 9.

DJA TO TESOM INTERFACE METHODOLOGY

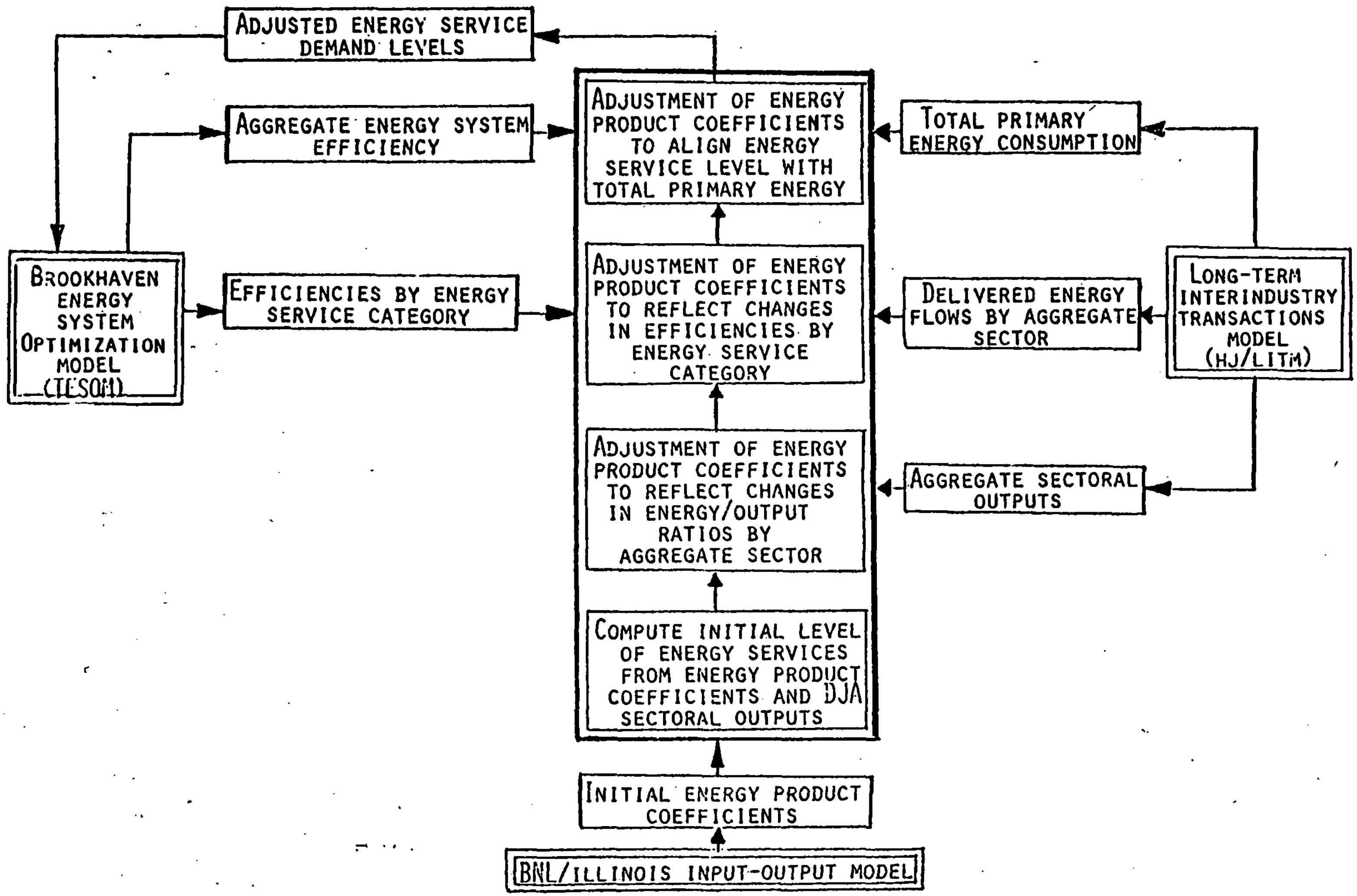


Figure 9

As utilized, the two models are naturally complementary: the DJA system models energy demand and economic effects; TESOM models energy supply and conversion but not energy demand. The two models, therefore, interface at energy demand with the DJA model covering from aggregate energy demand through the general economy and with TESOM covering from resources through energy demand. The linked system extends the coverage and applicability of either model. Further, the linked system provides a framework for the consistent analysis of the role of energy technologies, energy supply and conversion, energy use, and energy-economy interactions.

The LEAP Model System

The LEAP [1] model is a detailed, dynamic model of the supply and demand for energy in the United States. The methodology of the model was developed in 1973 to analyze synthetic fuel strategy for Gulf Oil Corporation and has since been extended and modified for use in the Department of Energy's long- range energy analysis. This section presents the current LEAP network known as ARC-78, although refinements to the model are on-going both in-house and through subcontracts.

Categorized as a general equilibrium model, LEAP uses a methodology for the coordinated decomposition of complex time-dependent optimization problems. The energy system is divided into a number of simpler submodels which are coordinated within the model structure. LEAP does not impose one universal goal where the allocation of resources and demand is determined by explicit optimization of a single objective function. Rather the modules in LEAP represent the solutions to the decentralized optimization problem. A recursive solution algorithm is used to coordinate the decentralized solution into an equilibrium solution.

The structure of the LEAP model can be illustrated by a network diagram, as shown in Figure 10. The ten major sectors each contain activities (or processes) connected by links that pass information through the network. Each process is characterized by a set of mathematical relations, both economic (based on historic and projected data) and subjective (based on expert judgment). These relations may be physical, describing how physical flows interact over time, or behavioral, describing human choices. The basic network describes the links among the processes. These links are expressed as flows of prices and quantities of energy products. Some links can also represent environmental controls, the relationship of the energy sector to the economy, and constraints on prices or quantities.

At the bottom of this network are processes describing primary resource supply: oil, gas, coal, uranium. Processes at the top of the network represent end-use demands for energy by sector: residential, commercial, industrial, transportation. In-between are other processes describing market behavior, energy conversion, and transportation. The two representations between supply and demand are the electrical utilities sector and the energy distribution sector. LEAP

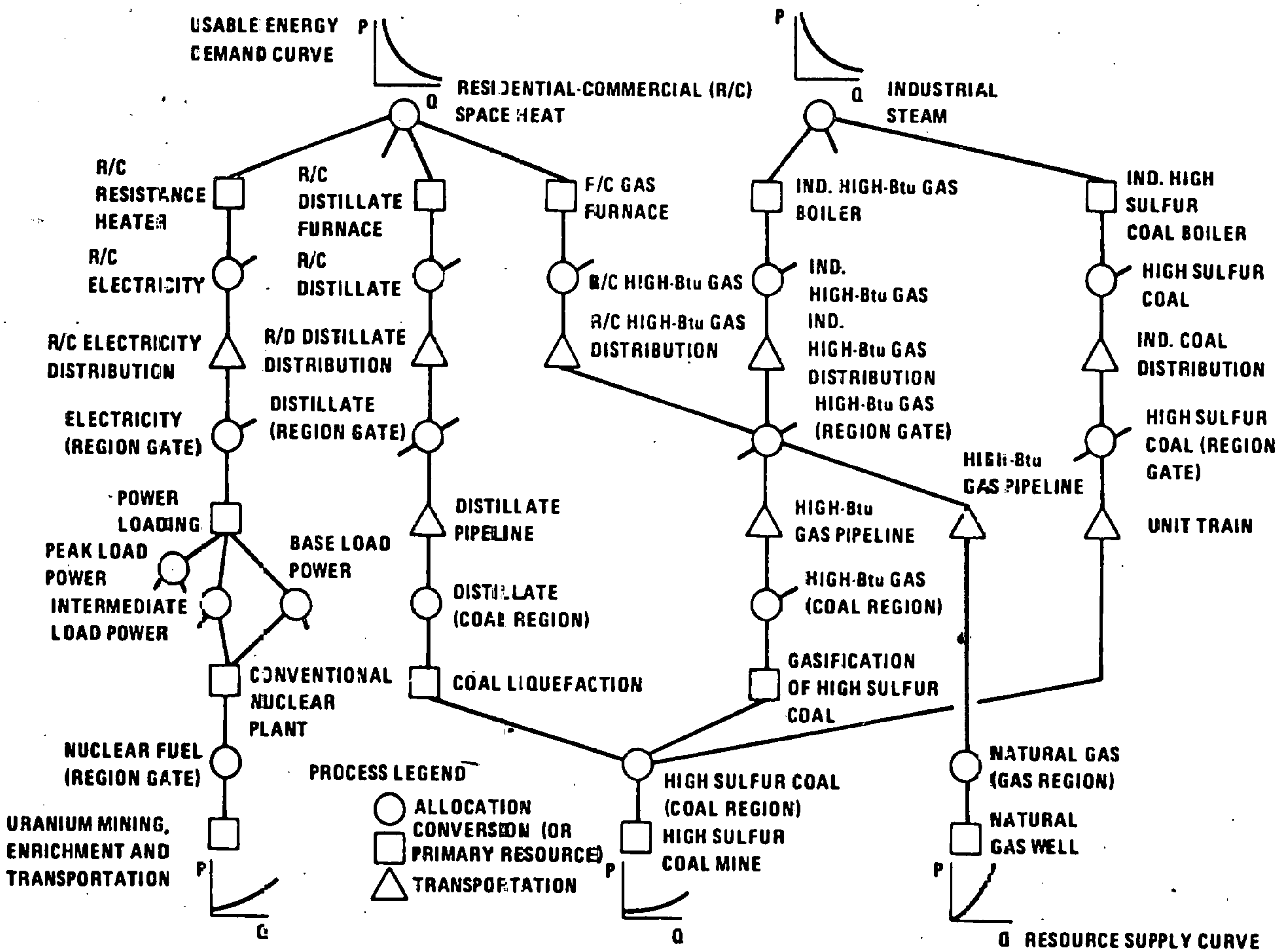

USABLE ENERGY
DEMAND CURVE
P
Q
RESIDENTIAL-COMMERCIAL (R/C)
SPACE HEAT
P
Q
INDUSTRIAL
STEAM
R/C
RESISTANCE
HEATER
R/C
DISTILLATE
FURNACE
F/C GAS
FURNACE
IND. HIGH-Btu GAS
BOILER
IND. HIGH
SULFUR
COAL BOILER
R/C
ELECTRICITY
R/C
DISTILLATE
R/C HIGH-Btu GAS
IND.
HIGH-Btu GAS
HIGH SULFUR
COAL
R/C ELECTRICITY
DISTRIBUTION
R/D DISTILLATE
DISTRIBUTION
R/C HIGH-Btu GAS
DISTRIBUTION
IND.
HIGH-Btu GAS
DISTRIBUTION
IND. COAL
DISTRIBUTION
ELECTRICITY
(REGION GATE)
DISTILLATE
(REGION GATE)
HIGH-Btu GAS
(REGION GATE)
HIGH SULFUR
COAL (REGION
GATE)
HIGH-Btu
GAS PIPELINE
POWER
LOADING
DISTILLATE
PIPELINE
HIGH-Btu
GAS PIPELINE
UNIT TRAIN
PEAK LOAD
POWER
BASE LOAD
POWER
INTERMEDIATE
LOAD POWER
DISTILLATE
(COAL REGION)
HIGH-Btu GAS
(COAL REGION)
CONVENTIONAL
NUCLEAR
PLANT
COAL LIQUEFACTION
GASIFICATION
OF HIGH SULFUR
COAL
NUCLEAR FUEL
(REGION GATE)
PROCESS LEGEND
ALLOCATION
CONVERSION (OR
PRIMARY RESOURCE)
TRANSPORTATION
HIGH SULFUR COAL
(COAL REGION)
HIGH SULFUR
COAL MINE
NATURAL GAS
(GAS REGION)
NATURAL
GAS WELL
URANIUM MINING,
ENRICHMENT AND
TRANSPORTATION
P
Q
P
Q
P
Q
RESOURCE SUPPLY CURVE

Figure 10

also includes an explicit representation of energy imports and exports.

The algorithm used to solve this generalized equilibrium model finds the set of prices and quantities that satisfies the physical and behavioral relations embodied in the processes, linkages, and as defined by the network. Because an explicit solution of the model is usually not possible, iterative techniques are used to successively adjust prices and quantities until a solution is found. Starting with initial estimates of prices and quantities for all energy processes, the LEAP algorithm makes two basic sweeps through the entire network. Tentative prices are computed on the upward iteration (holding quantities constant) and tentative quantities are computed on the downward iteration (holding prices constant). The resulting equilibrium solution reflects whatever market imperfections and human behavior are built into the processes. Moreover, the equilibrium solution is dynamic because the solution for a given time-period depends on the solutions in past and future time-periods.

The supply processes describe the production of primary energy resources, disaggregated into appropriate supply regions. These representations use long-run supply curves based on available geologic data and price assumptions. Prices are derived from the marginal cost of producing an additional quantity of energy plus an economic rent term that represents resource scarcity and short-run supply dynamics. LEAP models resource depletability in the economic sense that costs increase as depletion ensues. Technological change and learning effects on production and operating costs could partially offset these depletion based cost increases. Production decisions are based on each producer maximizing the present value of future profits. The central assumption of perfect foresight, or knowledge of all future prices, allows producers to withhold resources or shift production across time to maximize profit.

The end-use processes represent demands for various types of energy services such as fuel heat or vehicle miles. Unlike many energy models that use energy product demand as the final energy demand, LEAP represents the final demand in terms of services derived from projections of end-use consumption. Thus, the end-use demand model is not concerned with fuel or technology competition since these are treated in conversion and allocation processes. Energy service demand is described as a function of population, economic activity and price (marginal cost) of energy services. Basically, LEAP takes projections of aggregate economic activity and population growth and determines sector activity and the price elasticity of demand and each end-use service. The effect of price on energy demand is accounted for by constant, elasticity demand curves combined with a lagged adjustment process.

Many of the activities between primary energy supply and end-use demand represent conversion processes, which describe representative energy technologies. Model parameters account for technological change, thermal efficiency, and capital and operating cost changes. A capital cost premium is incurred for use of a technology before the date of commercial availability. The relations for a simple conversion process are straightforward, physical accounting flows of one input, a conversion process, and one output for an activity. A complex conversion process describes a multiple input or multiple output activity like electric power generation or oil refining. For example, the model must consider the fluctuating demand for electricity, the high cost of storing electricity, and the cost and efficiencies of different technologies available to generate electricity. In this case, the model uses a subnetwork composed of an electric power load disaggregation process, an allocation process for each load category, and several electric, power conversion processes.

Some other keys of LEAP include:

- The dynamic structure of the model spans the next 50 years. Within each of the process models, installation and retirement of facilities over time and, as mentioned above, in the case of primary resources, depletion over time are modeled.

- Plant capacity is distinguished from actual production, meaning that excess or insufficient capacity can occur in an industry or sector.

- Capacity expansion decisions depend on future prices, current capacity, and financial costs. The perception of future prices in LEAP can be varied from complete myopia to perfect information.

- The model includes a detailed treatment of debt and equity, financial flows, income taxes, investment tax credits, property taxes, and depreciation.

- Electric power demand is characterized by three loading categories: base, immediate, and peak. As fuel prices change and new technologies are introduced, utility plants are loaded to minimize the cost of electricity.

- The allocation processes use a continuous market share function which allows the user to select the degree of price sensitivity from most sensitive to most insensitive. In addition, this function contains parameters to capture intrinsic (non-price) discrimination among sellers on the part of buyers, and a behavioral lag term to reflect the time lag of changing market shares.

The market share model of supply-side competition, also utilized by FOSSIL2, represents a major distinction between LEAP and FOSSIL2, and PILOT/WEM, ETA-MACRO and BNL/DJA. In the first two models a cheaper product or technology captures only that fraction of a market for which it is probably cheapest, and then only after a time lag of up to 50 years. In the other supply-side models, the optimization methodologies embody other sophisticated, often classical, schemes to achieve smooth rates of technology penetration.

Interestingly, the supply-side market share model of LEAP can be described as the consequence characterizing the uncertainty in the competing technologies.

LEAP NETWORK

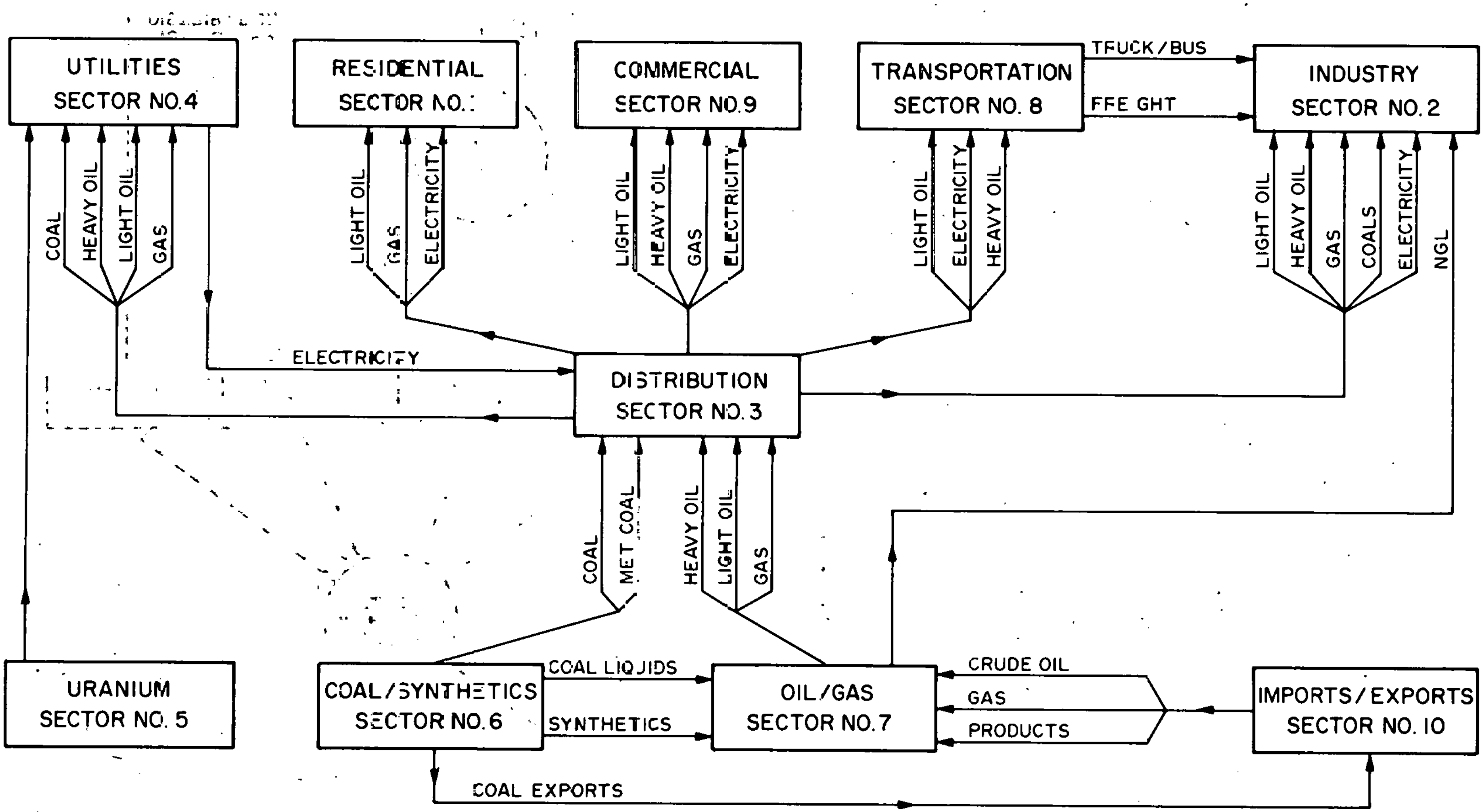


Figure 11

RESIDENTIAL SECTOR (NO. 1)

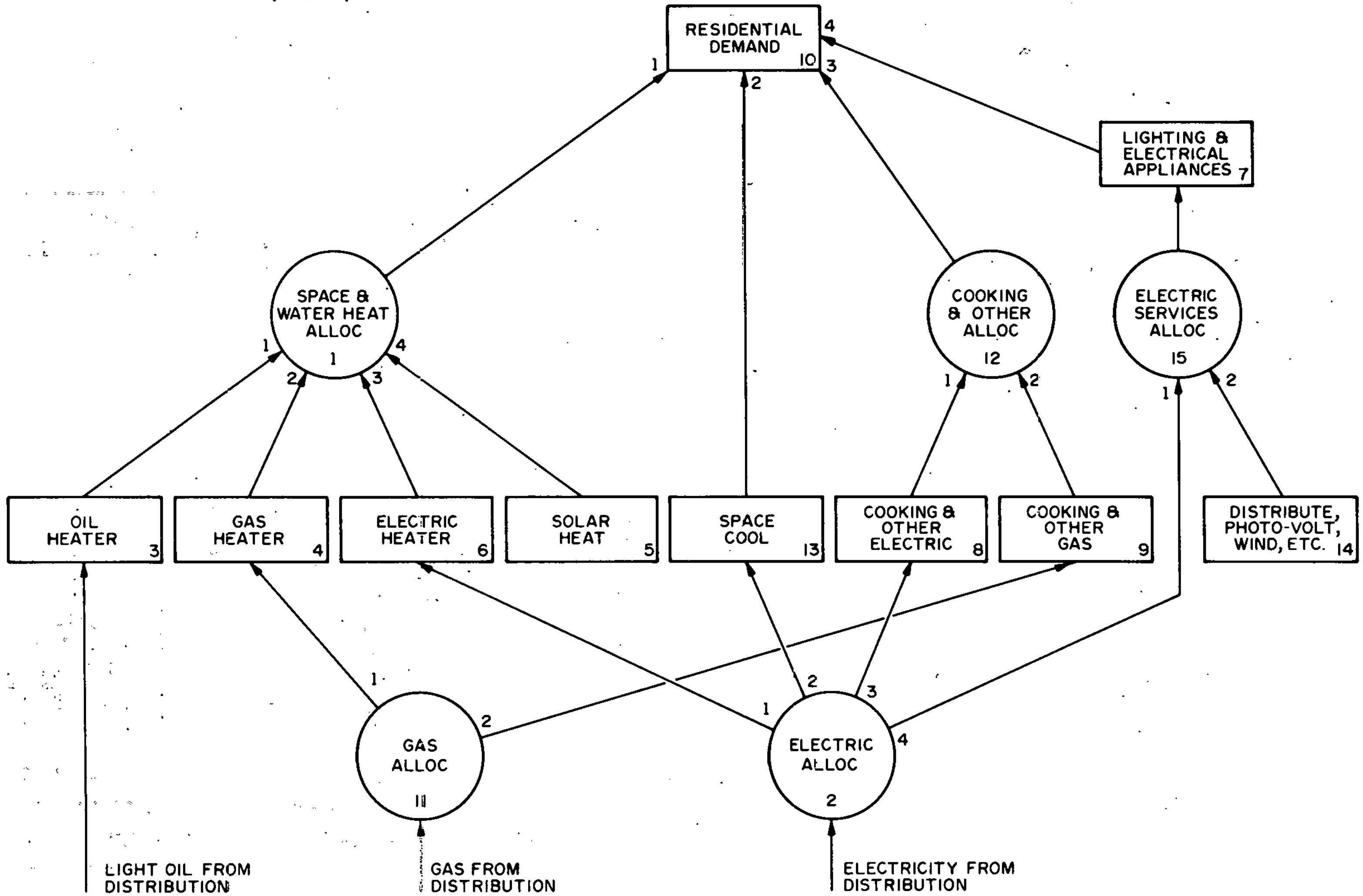
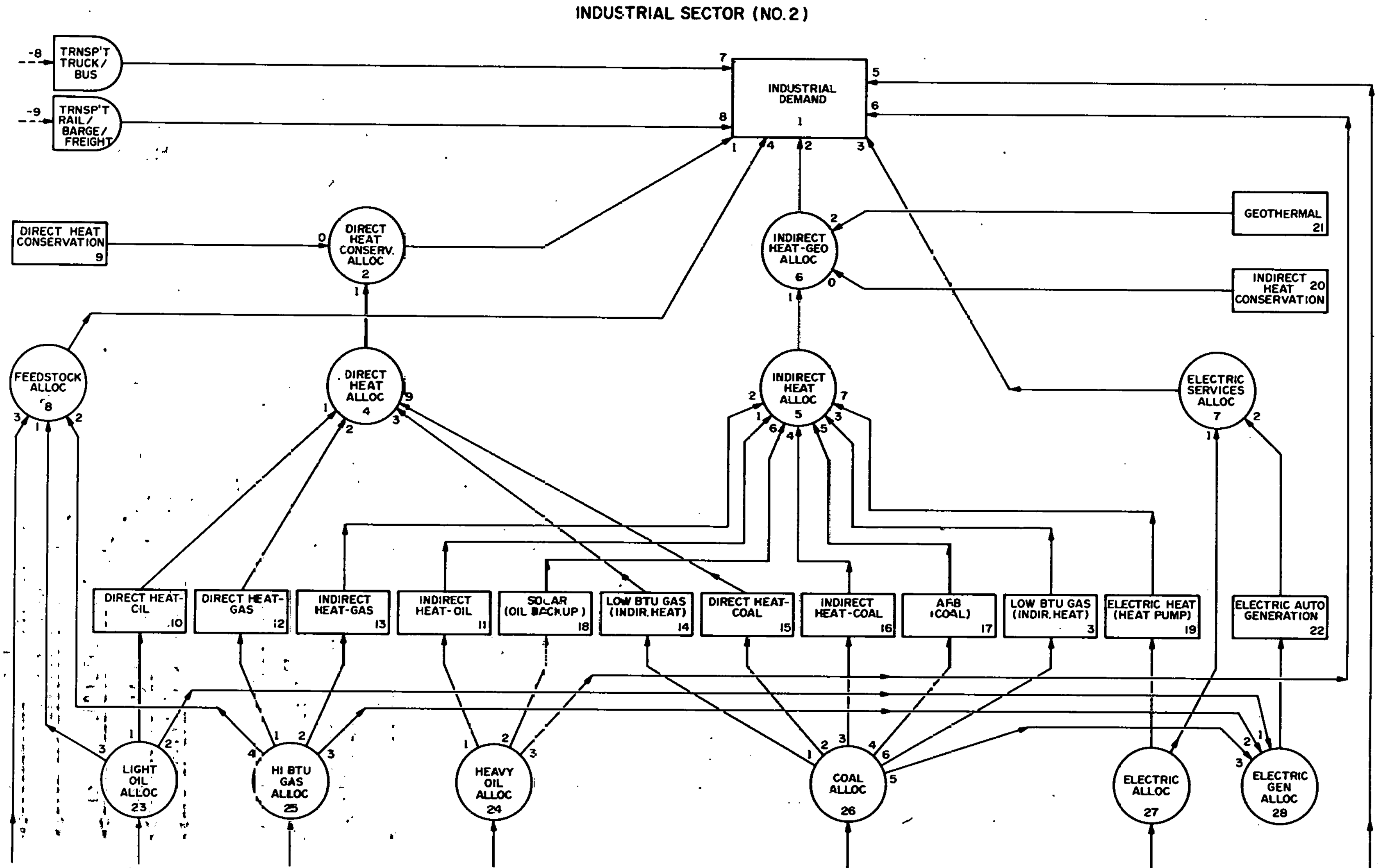


Figure 12



INDUSTRIAL SECTOR (NO.2)
TRNSP'T TRUCK/ BUS
TRNSP'T RAIL/ BARGE/ FREIGHT
INDUSTRIAL DEMAND 1
DIRECT HEAT CONSERVATION 9
DIRECT HEAT CONSERV. ALLOC 2
INDIRECT HEAT-GEO ALLOC 6
GEOTHERMAL 21
INDIRECT HEAT CONSERVATION 20
FEEDSTOCK ALLOC 8
DIRECT HEAT ALLOC 4
INDIRECT HEAT ALLOC 5
ELECTRIC SERVICES ALLOC 7
DIRECT HEAT-OIL 10
DIRECT HEAT-GAS 12
INDIRECT HEAT-GAS 13
INDIRECT HEAT-OIL 11
SOLAR (OIL BACKUP) 18
LOW BTU GAS (INDIR.HEAT) 14
DIRECT HEAT-COAL 15
INDIRECT HEAT-COAL 16
AFB (COAL) 17
LOW BTU GAS (INDIR.HEAT) 3
ELECTRIC HEAT (HEAT PUMP) 19
ELECTRIC AUTO GENERATION 22
LIGHT OIL ALLOC 23
HI BTU GAS ALLOC 25
HEAVY OIL ALLOC 24
COAL ALLOC 26
ELECTRIC ALLOC 27
ELECTRIC GEN ALLOC 28

Figure 13

DISTRIBUTION SECTOR (NO. 3)

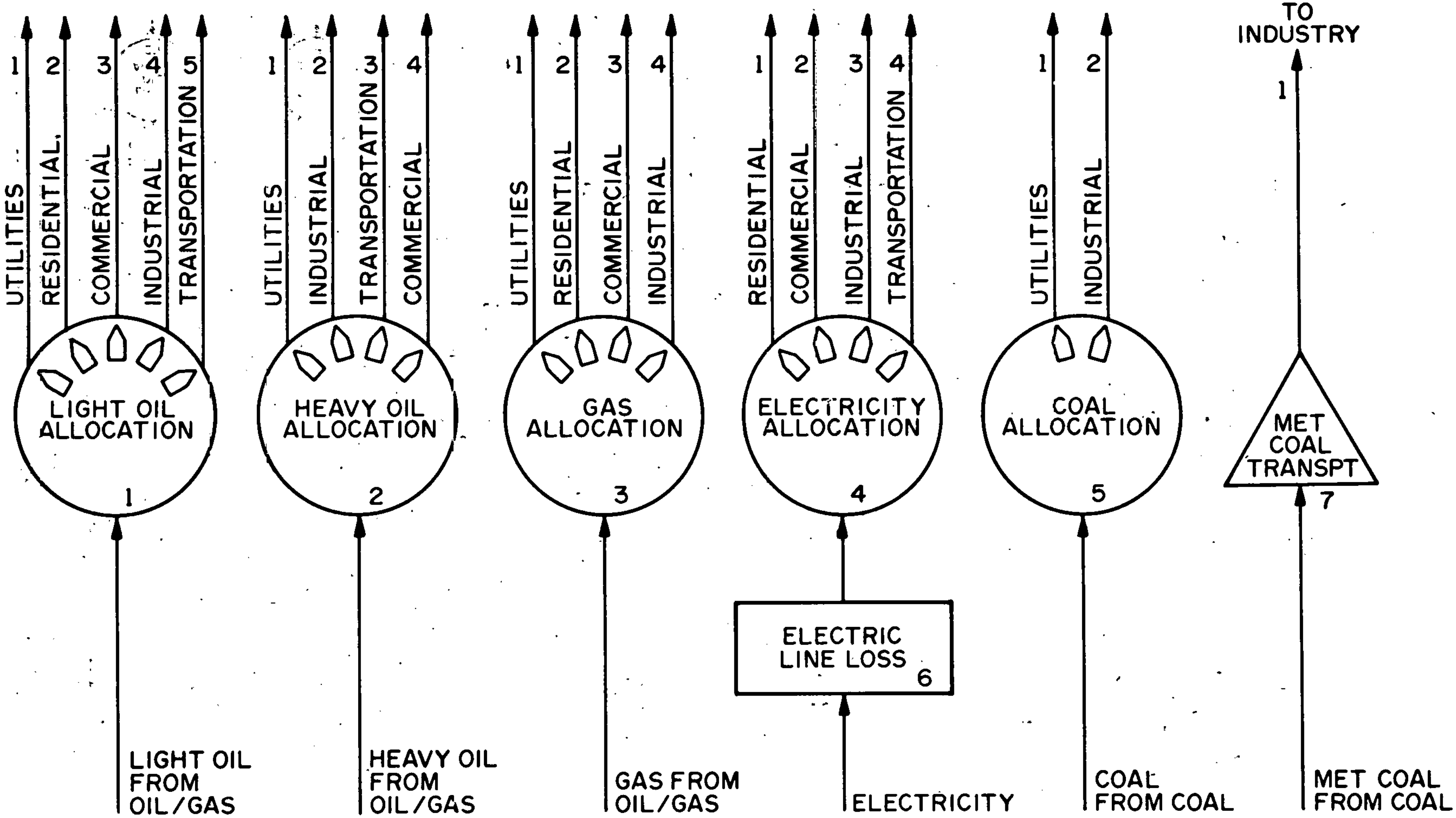


Figure 14

ELECTRICITY SECTOR (NO. 4)

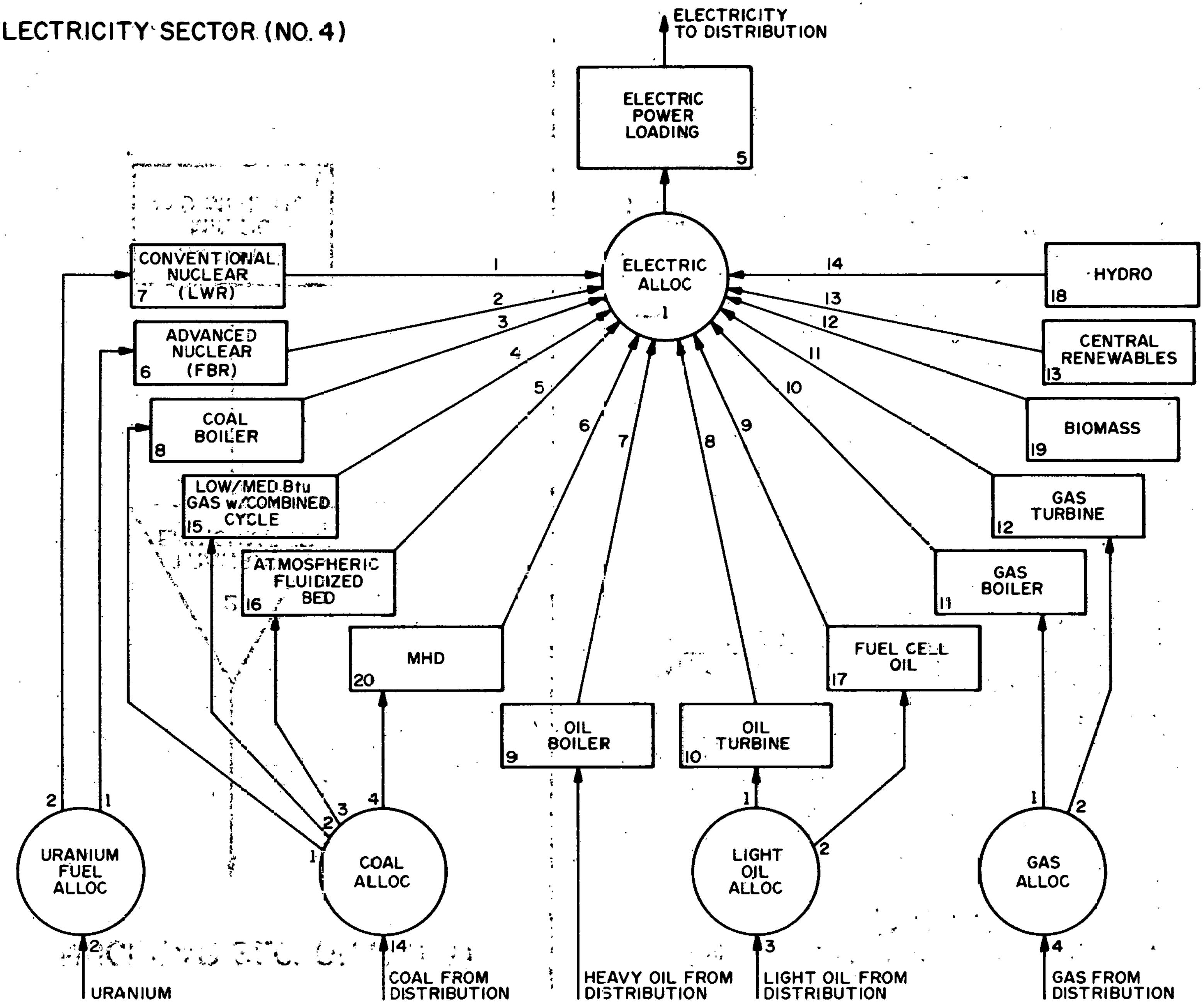


Figure 15

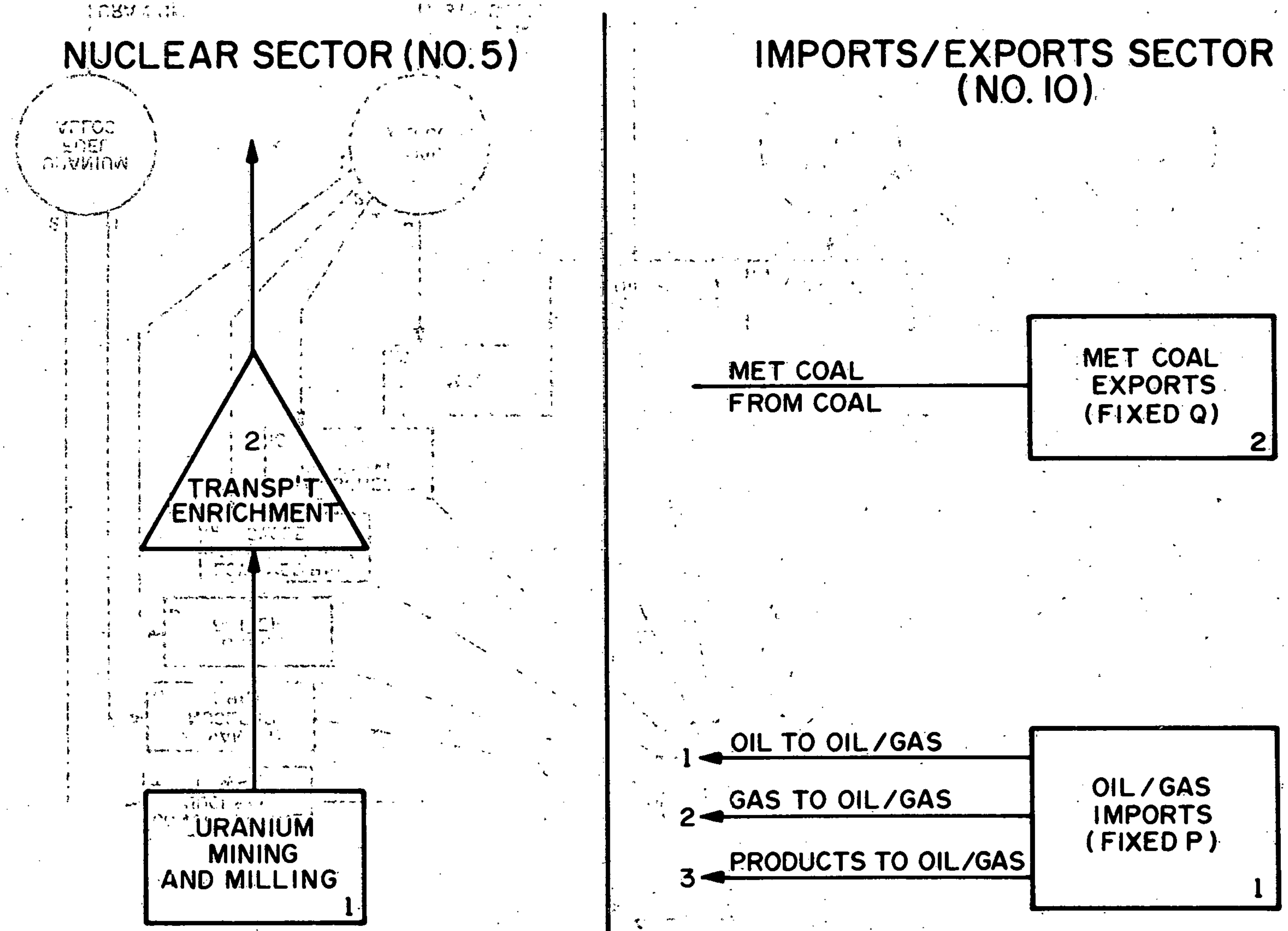

NUCLEAR SECTOR (NO. 5)
2
TRANSP'T ENRICHMENT
URANIUM MINING AND MILLING
1
IMPORTS/EXPORTS SECTOR (NO. 10)
MET COAL FROM COAL
MET COAL EXPORTS (FIXED Q)
2
1
OIL TO OIL/GAS
2
GAS TO OIL/GAS
3
PRODUCTS TO OIL/GAS
OIL/GAS IMPORTS (FIXED P)
1

Figure 16

COAL SECTOR (NO. 6)

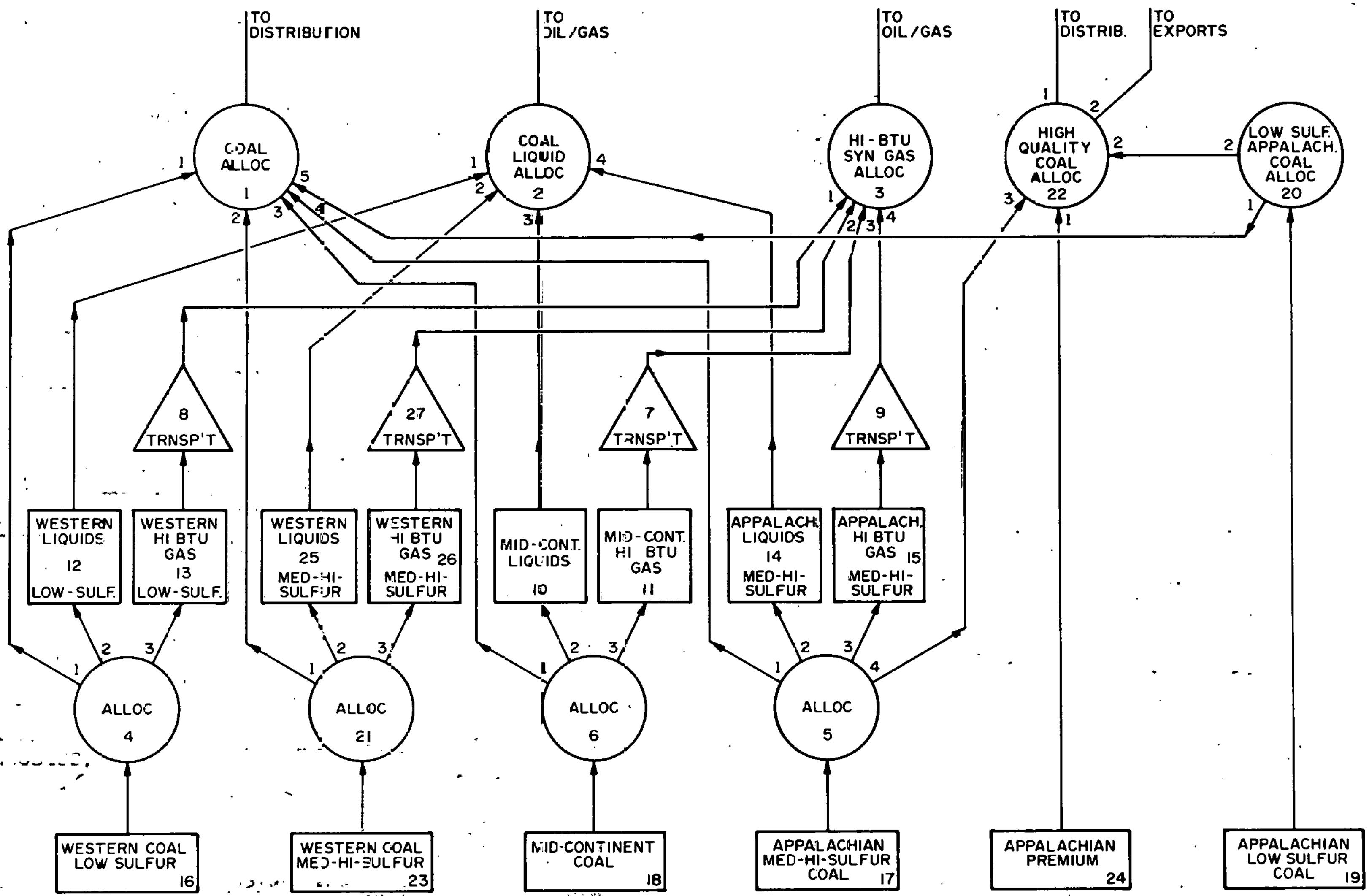


Figure 17

OIL/GAS SECTOR (NO.7)

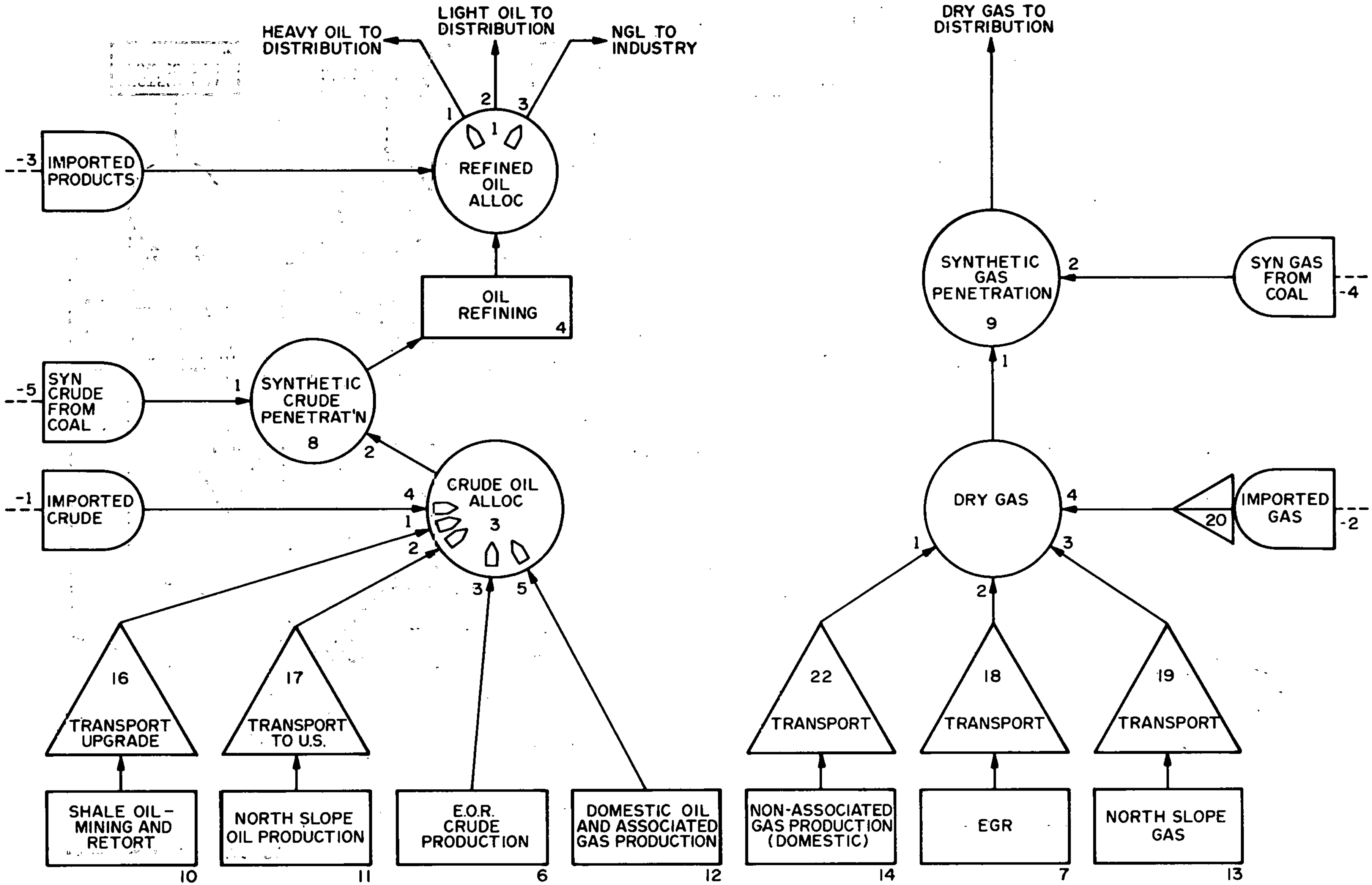


Figure 18

TRANSPORTATION SECTOR (NO. 8)

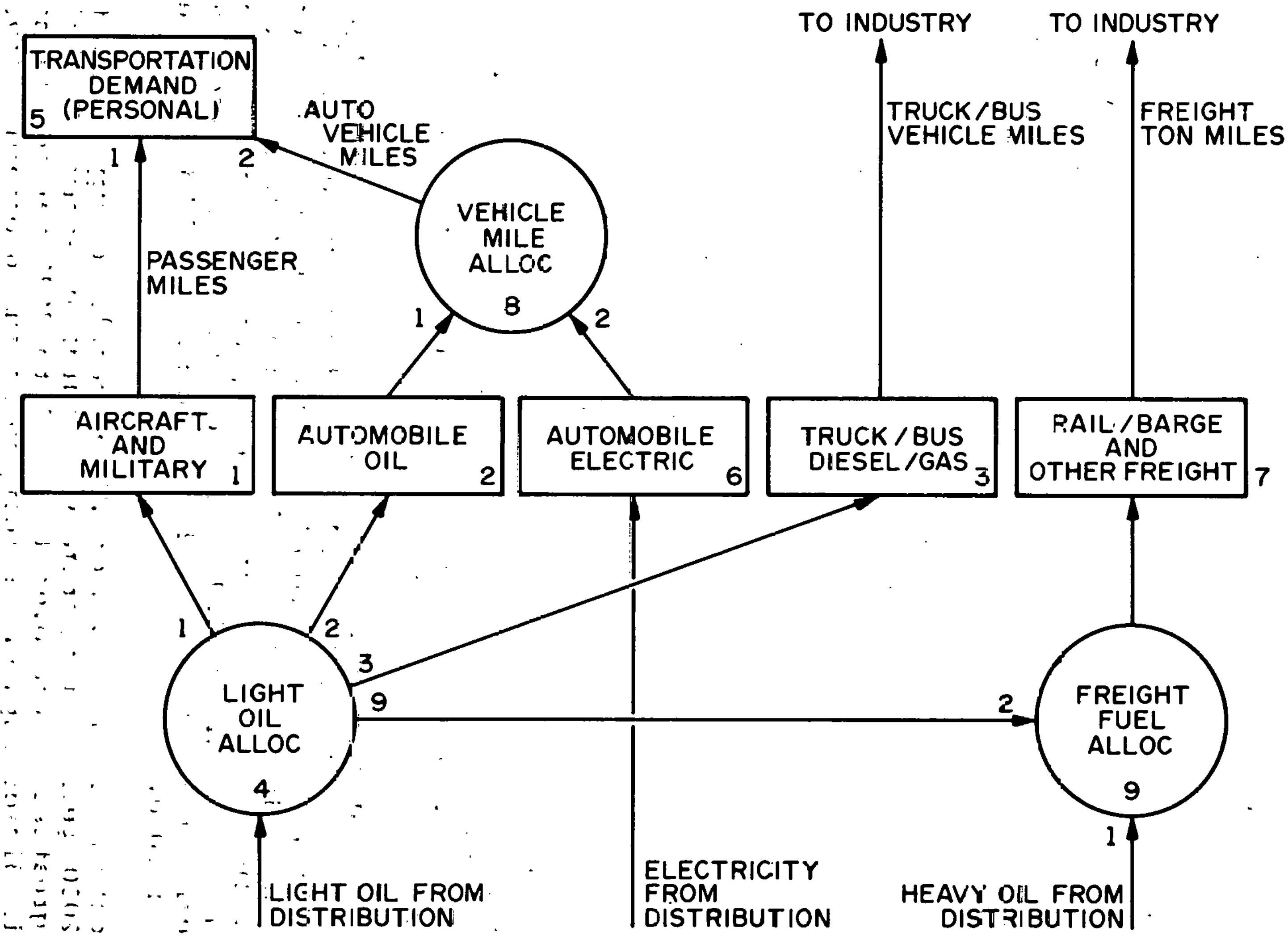


Figure 19

3. RESULTS

FOSSIL2

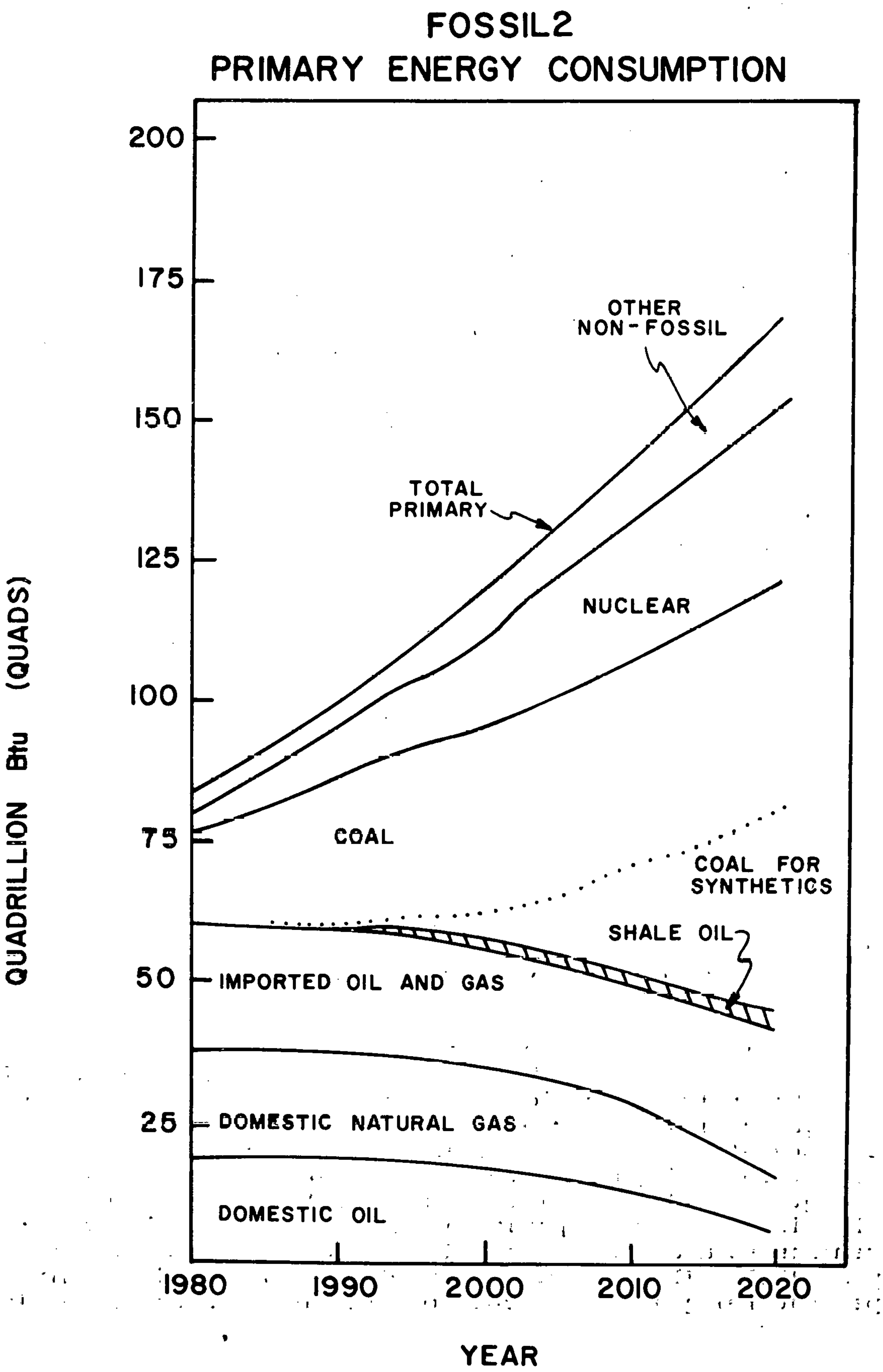
Primary Energy and Composition

The FOSSIL2 (1978) national energy model projected an average, annual growth rate in primary energy consumption of 1.9 percent over the 1977 to 2000 period and a somewhat slower rate of 1.6 percent from 2000 to 2020.

As primary energy usage increases from 75.7 quadrillion Btu in 1977 to 119.1 quads in 2000, there are significant shifts in its composition. The shares of domestic oil and gas and imported oil decline from 23.6, 24.0, and 24.1 percent, respectively, in 1977 to shares of only 14.7 percent for domestic oil in 2000 and 15.1 percent and 15.4 percent for oil import levels and domestic gas usage, respectively. These resources are displaced primarily by coal, nuclear, and other non-fossil energy sources. Coal usage in 2000 is estimated to be more than double its 1977 level of 14.1 quads and rises to 35.9 quads. This 4.1 percent average, annual growth rate in coal consumption is a result of both the projected increase in the share of electricity generated from coal and the rapid 10.0 percent average, annual growth in coal-based synthetics during this period. Nuclear inputs are projected to exhibit the greatest growth of all energy resource categories over the remainder of the century. Uranium consumption grows from 2.7 quads in 1977 to 15.7 quads in 2000 or at an average rate of 8.0 percent per annum. Other non-fossil electric inputs, which include hydroelectric, geothermal, solar, and wind inputs, grow more rapidly than total primary energy and rise from 2.3 quads in 1977 to 4.3 quads by the year 2000. Non-fossil direct inputs also increase over this period and account for 4.5 percent of total, primary energy consumption in 2000.

The major pattern evident in the FOSSIL2 primary energy projections over the 1977 to 2000 period appears to be a significant shift away from total oil and gas usage as its aggregate share declines from 73.1 percent to 48.6 percent. Coal and uranium are the primary fuels that substitute for oil and gas over this period as the combined share of coal and nuclear inputs rises from 21.7 percent in 1977 to 43.3 percent in 2000.

In contrast to the rapid growth of nuclear energy during the pre-2000 period, the primary resource category exhibiting the greatest growth over the 2000 to 2020 period, is non-fossil direct inputs. Direct solar and geothermal levels grow at an average annual rate of 5.6 percent from 5.3 quads



FOSSIL2
PRIMARY ENERGY CONSUMPTION
QUADRILLION Btu (QUADS)
200
175
150
125
100
75
50
25
OTHER NON-FOSSIL
TOTAL PRIMARY
NUCLEAR
COAL
COAL FOR SYNTHETICS
SHALE OIL
IMPORTED OIL AND GAS
DOMESTIC NATURAL GAS
DOMESTIC OIL
1980
1990
2000
2010
2020
YEAR

Figure 20

in 2000 to 15.7 quads by 2020. The year 2000 share of total non-fossil energy, including nuclear (21.2 percent) continues to rise to 27.1 percent by the year 2020. However, the growth rate of nuclear inputs is significantly slower during the 2000 to 2020 period increasing at an average annual rate of only 2.1 percent per annum as compared with its pre-2000 annual growth rate of 8.0 percent. Domestic oil production is reduced substantially over the 2000 to 2020 period and declines at an average rate of 5.5 percent per year from 17.5 quads in 2000 to only 6.0 quads by 2020. Similarly, domestic gas production falls sharply from 18.3 quads to 10.4 quads. As the aggregate share of oil and gas declines to 29.5 percent in 2020, coal's share increases to 43.4 percent of total primary energy and accounts for the largest share of primary resource consumption over the 2000 to 2020 period.

Electric Generation

In the FOSSIL2 energy projection, electricity generation is anticipated to rise at an average annual rate of 3.0 percent from 1977 to 2000 and then continue to grow at a moderately slower rate of 1.7 percent per annum through the year 2020. Electricity generated from coal increases in absolute terms from 3.6 quadrillion Btu in 1980 to 7.5 quads by 2000, but coal only marginally increases its share of total generation during the pre-2000 period. After 2000 coal generated electricity rises at 2.4 percent per year through 2020, and its share increases slightly from 48.1 percent in 2000 to 51.9 percent in 2020. The proportions of total, coal generated electricity provided by conventional coal steam plants, coal-combined cycle plants, and coal fluidized bed combustion (FBC) plants vary over time. In 2000, conventional coal plants provide 6.1 quads or 81.3 percent of the total 7.5 quads of coal-generated electricity, combined-cycle generation accounts for 14.7 percent, and coal FBC generation accounts for 4.0 percent. By 2020, however, the shares of coal-combined cycle generation and coal FBC generation rise to 45.8 percent and 5.8 percent, respectively, of total coal generated electricity. The increased usage of these more efficient coal generating technologies results in the reduction of conventional coal generation to 5.8 quads or 48.3 percent of total coal generated electricity by 2020. Gas-fired electricity generation is significantly reduced during the pre-2000 period from a level of 1.1 quads in 1980 to 0.2 quads in 2000. Gas-fired electricity is not totally phased-out in the post-2000 period; it remains at a constant minimal level of 0.1 quads through the year 2020. Electricity generated from oil declines only 1.0 percent per year from 1980 to 2000, but its share declines from 18.6 percent to only 8.3 percent over this period. After 2000, oil-fired electricity generation decreases more rapidly at an annual rate of 2.5 percent as nuclear and coal generated electricity accounts for an increasingly larger share of total generation. Nuclear electricity, generated solely by the light water reactor (LWR) technology, is projected to provide 32.1 percent of total electricity generation in 2000 and 33.3 percent by 2020 as contrasted with its 1980 share of 15.1 percent. Other non-fossil electric inputs rise continuously from 1977 through 2020 though at a slower rate than total generation. Therefore, the aggregate share of hydro-electric, geothermal, solar, and wind generated electricity declines from 11.6 percent in electricity declines from 11.6 percent in 1980 to 9.6 percent in 2000 and then rises to 10.4 percent in the year 2020. The degree of electrification, as measured by the ratio of total inputs for electricity generation versus total, primary energy consumption, rises from 29.5 percent in 1977 to 40.1 percent by 2000. In the post-2000 period the degree of electrification reaches a peak in the year 2010 of 42.1 percent and is then reduced to 40.8 percent by the year 2020.

Non-electric Advanced Supply Technologies

The levels of new non-electric technologies projected by FOSSIL2 indicate that the most significant growth occurs in the production of coal-based synthetics. Total liquids production, which includes methanol and coal liquids, increases from 0.4 quads in 1980 to 1.9 quads in 2000 or at an average annual rate of 8.1 percent. In 1980 methanol output level of 0.4 quads increases to 0.5 quads in 1985 and remains constant through 2020. Coal liquids are introduced in 1990 and account for 73.7 percent of synthetic liquids production by 2000. Total,synthetic gas output from coal in 2000 is projected to be 1.8 quads, primarily from the production of medium-Btu gas.

In the post-2000 period, coal liquids grow rapidly at 9.1 percent annually while methanol production exhibits no increased growth. Total coal-based, synthetic liquids in 2020 reach 8.5 quads and account for 43.4 percent of total coalbased synthetics production. Production of both high-Btu and medium-Btu coal gas are accelerated after 2000, and total synthetic gas output reaches 11.1 quads in the year 2020. The production of these synthetic liquid and gaseous fuels is a major contributing factor to the increasing share of coal in primary energy consumption and the corresponding reductions in the shares of imported oil and gas over this period.

Another category of non-electric, new technology implementation contained in the FOSSIL2 projection is non-fossil direct, e.g., direct solar and geothermal heating. The inputs to these devices grow at an average annual rate of 5.2 percent per year from 1977 (1.8 quads) to 2020 (15.7 quads).

Primary Energy and Composition

In the PILOT model system, primary energy is projected to reach 128.6 quads in 2000 and grow at an average annual rate of 2.3 percent from 1977 to 2000 and at a much slower rate of 1.3 percent per annum in the post-2000 period. The evident trend in the composition of primary energy over the 1977 to 2005 period for which the model was run is the substitution of coal, nuclear, and non-fossil inputs for domestic and imported oil and gas. Domestic oil's share of total primary consumption of 24.2 percent in 1977 declines to 13.5 percent by 2005. Domestic gas shows a similar reduction in its share as it accounts for only 13.3 percent of total primary energy in the year 2005 in contrast with its 1977 share of 24.6 percent. Aggregate imports of oil and gas, which comprise 26.1 percent of energy use in 1977, are reduced to 12.6 percent as the reliance on oil and gas in earlier years is replaced by greater dependence on coal and nuclear sources of energy by 2000. Shale oil enters the system at a level of 0.1 quad in 1990 and grows to 2.8 quads by the year 2025.

Coal becomes the dominant fuel in the post-2000 period and accounts for 36.0 percent of aggregate, primary energy use in 2005, approximately doubling its 1977 share. In 2005 49.3 quads of the total 137.0 quad demand for primary energy is provided by coal. Nuclear energy is projected to grow at a rate of 7.2 percent from 1977 through 2000 and accelerates its growth further to an annual rate of 8.4 percent after 2000. By 2005 its share of total energy rises to 14.5 percent as nuclear inputs grow from 13.3 quads in 2000 to 19.9 quads by 2005.

Non-fossil electric sources, which include hydroelectric and solar energy, grow at 4.3 percent per annum through the year 2000 and more rapidly, at a rate of 10.1 percent, over the next five years to reach a total share of 7.0 percent in 2005. Direct non-fossil inputs also increase over the projection period but account for only a small share--1.1 percent--of total energy use by the year 2005. In addition to the shift towards greater use of coal and uranium over time, the increased growth of non-fossil electric and direct inputs indicates a trend towards greater use of renewable energy.

Electric Generation

Total electricity generation is projected to grow at an

PILOT MODELING SYSTEM
PRIMARY ENERGY CONSUMPTION

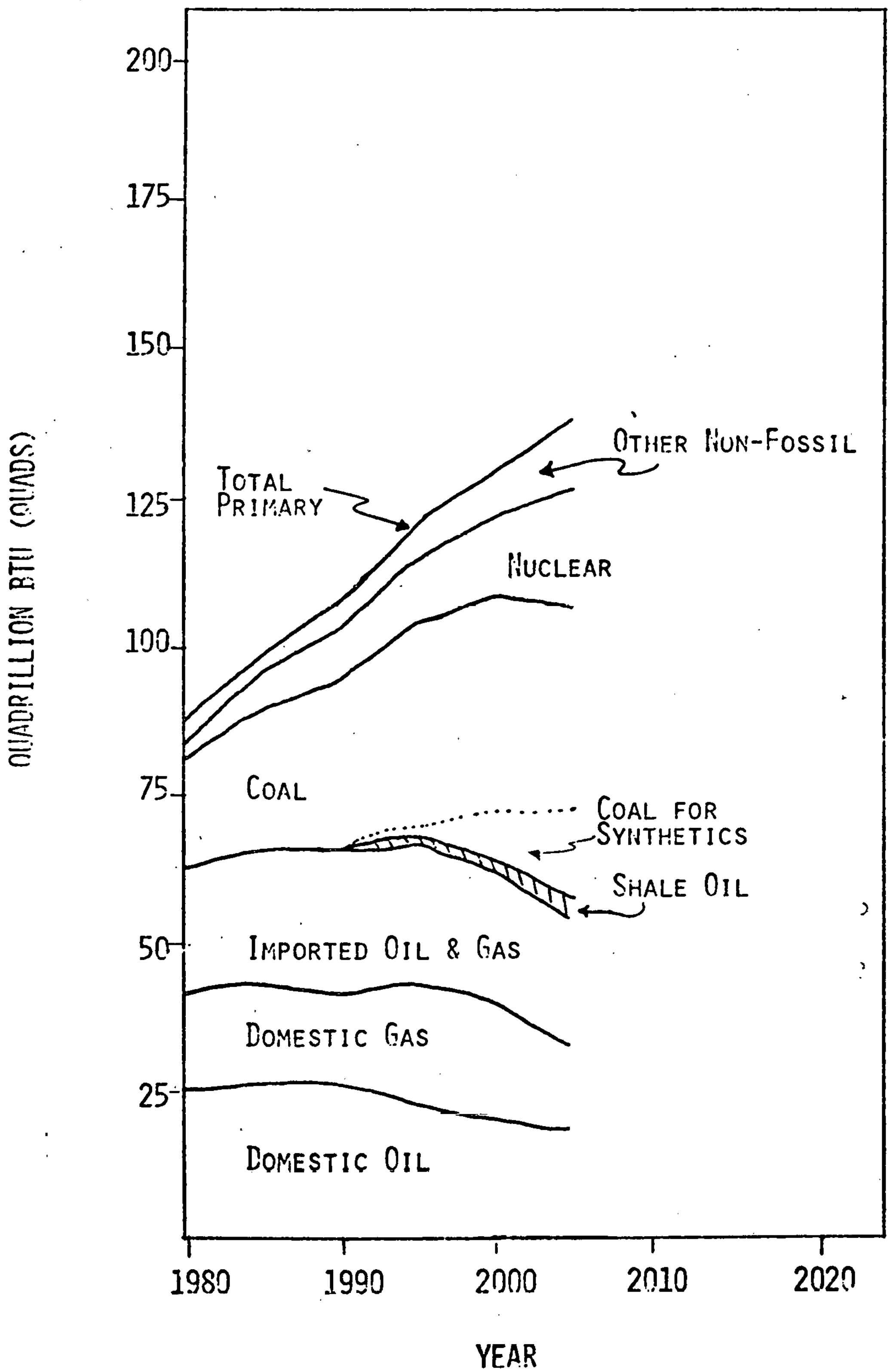


Figure 21

annual rate of 3.1 percent over the 1977 to 2000 period reaching 14.5 quads. This trend slows to 2.1 percent per year from 2000 to 2005 as total primary energy consumption growth slows. Total electrification increases over the projection period with 30.2 percent of primary energy going to electric generation in 1977, 33.0 percent in 2000, and 34.6 percent in 2005. Nuclear generation (light water reactors) grows the most rapidly at rates of 7.4 percent per year in the pre-2000 period and 8.5 percent per year in the post-2000 period yielding 4.4 quads of electric generation in 2000 and 6.6 quads in 2005. These levels provide 30.1 percent and 40.8 percent of electric generating capacity in 2000 and 2005 respectively. Hydroelectric generation grows at an annual rate of 1.6 percent in the pre-2000 period reaching 1.1 quads and remains at that level through 2005. Oil and gas generation declines significantly over the projection period with its share of total generation falling from 31.2 percent in 1977 to 5.0 percent in 2000 and 2005. Coal electric generation grows through 2000 reaching 8.3 quads in that year but falls to 7.2 quads in 2005 as nuclear generation assumes an ever increasing share. In fact, coal's share of total generation begins falling after 1995 from 59.5 percent in that year to 57.0 percent in 2000 and 45.0 percent in 2005 as it yields ground to nuclear generation. Solar electric generation provides less than 0.5 percent of the total generation in 2000 and grows to 2.4 percent (0.4 quads) in 2005.

Non-electric Advanced Supply Technologies

Shale oil production is projected to begin in 1990 and grow at an annual rate of 28.5 percent reaching 1.5 quads in 2000. After 2000 this growth slows to 13.6 percent per year. Coal liquids enter the system in the year 2000 at the (EIA/ARC) suggested upper bound of 3.7 quads and increase to 6.8 quads in 2005. In 1995 coal gasification produces 0.8 quads of energy and in 2000 and 2005 provides 1.6 quads and 3.2 quads, respectively, the suggested (EIA/ARC) upper bounds. Residential solar energy use becomes available in 1980 and grows at an annual rate of 9.6 percent to 2000 (1.4 quads). The AES is a model-specified technology which absorbs some requirements for liquid and gaseous fuels beyond the availabilities of the conventional and synthetic sources. The price at which the AES becomes available is $\$5/10^6$ Btu (1978$). The AES serves to represent advanced technologies, such as biomass conversion, not represented explicitly in the energy supply submodel. Its penetration is quantity limited. The AES penetrates the system in 1995 for gas at a level of 0.7 quads and supplies 2.6 quads and 1.9 quads in 2000 and 2005 respectively. The AES for oil enters in 2005 at 3.4 quads.

Demand Analysis

The PILOT model system provides a projection of consumer energy use for four end-use categories: space heating, air conditioning, other residential, and automobiles. Total use of energy for these categories of demand is projected to increase only 3.5 quads from 1980 to 2005 or at 0.6 percent per annum. The structure of demands also appears to stay relatively constant although small changes in shares for each category occur over the twenty-five year period. Space heating, which accounts for 30.2 percent of demand in 1980, is estimated to stay even until 1990 and, thereafter, to decrease to a 28 percent share by 2005. Air conditioning increases its share from 1.5 percent in 1980 to 2.3 percent in 2005 and is the demand category which shows the most rapid rate of growth at 2.1 percent per year. Other residential demand rises from 13.6 percent of demand to 17.7 percent while automobile demand stays relatively constant. Auto demand in 1980 is estimated to be 12.4 quads with an average fleet efficiency of 15.6 miles per gallon. By 2005, the average efficiency of automobiles is projected to attain 29.8 miles per gallon. Automobile demand increases at a rate of 0.3 percent per year to 13.2 quads in 2005 and maintains a 53.1 percent share of total end-use demand.

ETA-MACRO [11]

Primary Energy and Composition

Primary energy consumption is projected to reach levels of 122.3 quads in 2000 and 226.1 quads in 2030 yielding an average annual growth rate of 2.1 percent over the 1977 to 2030 period. The level of domestic oil and gas usage declines from 36.9 quads in 1977 to 33.0 quads in 2000 and 12.7 quads in 2030. Over the 2000-2030 period this decline occurs at a constant annual rate of 3.1 percent reflecting the bounds placed on domestic oil and gas availability. Imports of oil and gas increase slightly in the 1977-2000 period, rising from 19.7 to 22.4 quads, although the share of total imports declines from 26.1 percent to 18.3 percent in 2000 and to zero by 2020. Shale oil contributes 2.0 quads to primary energy consumption in each year from 2000 to 2030. Total conventional liquids (oil, gas, and shale oil) comprise 74.8 percent, 46.9 percent, and 6.5 percent of total primary consumption in 1977, 2000, and 2030 respectively. The decreased importance of conventional liquids in primary consumption is due to the phasing out of non-coal fossil electric generation and the substitution of synthetic fuels for non-electric uses.

Coal usage increases over the projection period from 14.1 quads in 1977 to 43.4 quads in 2000 and 102.6 quads in 2030, rising at an average annual rate of 5.0 percent in the 1977 to 2000 period and 2.9 percent thereafter. Coal's contribution to primary energy consumption increases from 18.4 percent in 1977 to 47.3 percent in 2000 but declines to 45.4 percent in 2030. The increased importance of coal in 2020 results from the higher degree of electrification of the energy system and the rising production of coal-based synthetic fuels. The decline in coal's share from 2020 to 2030 is due largely to the decrease in electrification over that period. Nuclear energy grows at annual rates of 6.8 percent and 5.0 percent over the pre- and post-2000 periods respectively. Nuclear's share of total primary energy usage increases from 3.6 percent in 1977 to 10.2 percent in 2000 and 23.6 percent in 2030. Advanced electric systems (breeder fission, fusion, and solar or hybrid) contribute 0.3 quads in 2020 and 3.2 quads in 2030 representing 0.2 percent and 1.4 percent of total primary energy in those years. Hydroelectric grows from 2.3 quads in 1977 to 7.0 quads in 2000 and remains at that level through 2025. Geothermal makes no contribution to primary energy usage being uneconomic at the cost assumptions specified. The "backstop" (non-electric) energy source rises from 2.0 quads in 2000 to 45.3

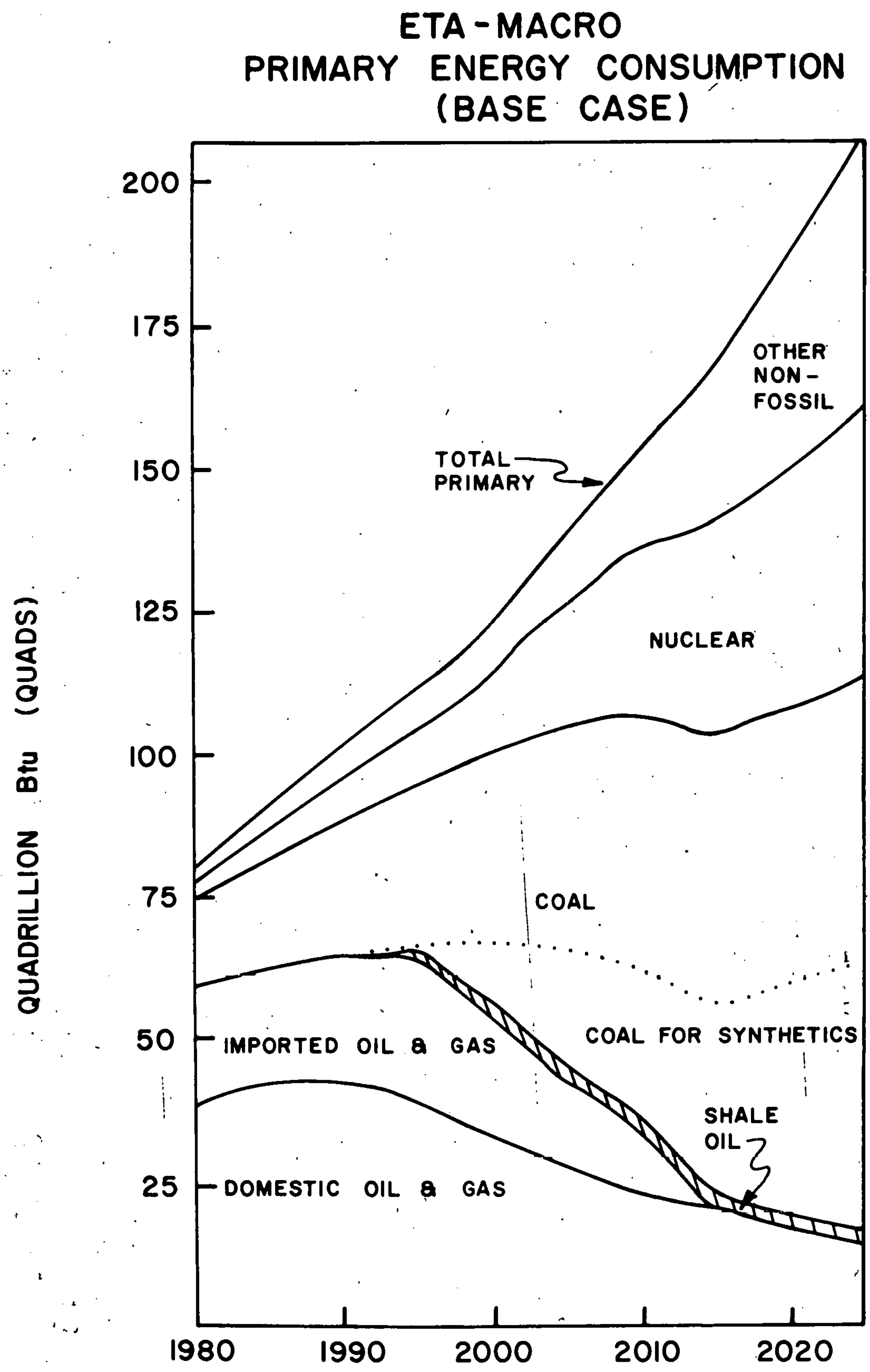

ETA-MACRO
PRIMARY ENERGY CONSUMPTION
(BASE CASE)
QUADRILLION Btu (QUADS)
200
175
150
125
100
75
50
25
1980
1990
2000
2010
2020
OTHER NON-FOSSIL
TOTAL PRIMARY
NUCLEAR
COAL
COAL FOR SYNTHETICS
IMPORTED OIL & GAS
SHALE OIL
DOMESTIC OIL & GAS

Figure 22

quads in 2030 or at an annual growth rate of 13.3 percent. The backstop provides 20.0 percent of primary energy consumption in 2030.

Over the projection period the share of oil and gas declines significantly as the system relies increasingly on coal, nuclear, and the backstop technology. If one assumes, however, that the major share of the backstop (non-electric) is similar to conventional fossil liquids (or is replacing them over time), then the share of primary energy providing "liquids" (oil, gas, shale oil, coal synthetics, and the backstop) declines from 74.8 percent in 1977 to 57.6 percent in 2000. After 2000 the "liquids" share stays relatively constant at about 50 percent of total primary energy. Thus, while "liquids" become less important over the medium term (until 2000), the availability of the backstop and synthetic fuels allows the system to maintain a relatively large dependence on "liquids."

Electric Generation

Electricity generation is projected to grow at annual rates of 3.1 percent and 2.7 percent over the 1977 to 2000 and 2000 to 2030 periods, respectively, with generation levels of 7.2 quads in 1977, 14.7 quads in 2000, and 32.4 quads in 2030. While the growth in electrification is slower over the post-2000 period than over the pre-2000 period, electric generation grows very rapidly from 2000 to 2010 (4.7 percent per year) and much more slowly from 2020 to 2030 (1.4 percent per year). This seems to be highly correlated to the reduction in the GNP growth rate. Hydroelectric generation grows from 0.8 quads in 1977 to 2.4 quads in 2000 and remains at that level through 2030. Coal's share of electric generation rises from 46.6 percent in 1977 to about 51 percent in 2000 as oil and gas generating capacity declines. After 2000, as nuclear assumes a larger role, coal's share of electric generation declines to 33.1 percent in 2030. However, the level of coal electric generation rises through 2020 to 11.6 quads and then falls in 2030 to 10.6 quads as the degree of electrification declines over that period. Conventional coal steam generation is gradually replaced by coal-combined cycle generation. Nuclear electricity provided by light water reactors assumes an ever increasing role in electricity generation rising from 0.9 quads in 1977 to 4.4 quads in 2000 and 18.1 quads in 2030. These levels represent shares of total electric generation of 11.6 percent, 29.2 percent, and 56.2 percent in the respective years. Advanced electric generation systems (breeder fission, fusion, and solar or hybrid) provide less than 1 percent of electric generation capacity in 2020 and 3.3 percent in 2030.

Non-electric Advanced Supply Technologies

Coal synthetic fuels are modeled with the efficiency and cost assumptions for the advanced, western, high-Btu, coal gasification system from the EIA/ARC guidelines. The penetration levels of synthetic fuels rise from 0.5 quads in 1990 to 8.3 quads in 2000 and 40.0 quads (the EIA/ARC guideline limit for all coal synthetics) in 2030. The backstop (non-electric) technology enters the projection in 2000 at 2.0 quads, but this level is forced into the solution as the backstop is not competitive with oil imports in that year. After 2000 the backstop source is at its permissible upper bound through 2020 and continues to grow after that year reaching 45.3 quads or 20.0 percent of primary energy consumption in 2030.

The backstop represents a chatch-all characterization of supply and conservation sources that would be economic at the price of $5 per million Btu (1978 $). Thus the high primary demand of 226.1 quads by 2030 could include conservation options equal to 45.3 quads of primary equivalent.

Primary Energy and Composition

In the BNL/DJA model system, aggregate, primary energy consumption is projected to grow at an average annual rate of 1.9 percent during the 1977 to 2000 period to a level of 117.3 quads in 2000. Energy consumption after the year 2000 grows at a more moderate rate of 1.5 percent per annum and reaches 170.3 quads in the year 2025. The pattern of energy use changes significantly over the 1977 to 2025 forecast period. The 1977 aggregate share of oil and gas imports declines from 26.1 percent of total primary energy to 10.3 percent in 2000 as these resources are displaced by more intensive use of coal, uranium, and non-fossil energy sources. Coal usage increases from its 1977 level of 14.1 quads at an annual rate of 5.1 percent to 44.6 quads in 2000. This growth is in accordance with the introduction of coal-based synthetic fuel production and the shift over this period from oil and gas-fired electric generation to coal-fired plants.

Nuclear inputs increase at an average annual rate of 6.7 percent over the 1977 to 2000 period, from 2.7 quads to 11.7 quads, and account for 10.0 percent of total primary use in 2000. Non-fossil electric inputs rise from 2.3 quads in 1977 to 6.9 quads in 2000 as hydroelectric, solar, and wind electric systems increase their aggregate share to 5.8 percent by 2000. Shale oil production reaches a level of 1.0 quad in 2000 but constitutes only a small share (less than one percent) of total primary energy in the pre-2000 period. Direct solar and geothermal heating rises from a 1980 level of 0.2 quads to 2.0 quads by 2000 as renewable energy sources substitute for depleted oil and gas resources. The increased levels projected for wood heating and electric generation result in the growth of the renewable, primary, wood resource usage from 0.5 quads in 1980 to 1.6 quads by 2000.

In the post-2000 period, coal maintains the largest share of total primary energy and rises from 44.6 quads in 2000 to 89.8 quads, or 52.7 percent of total primary consumption, by 2025. Nuclear energy continues to grow after 2000 but at a much slower rate than the 6.7 percent per year growth indicated for the pre-2000 period. From a 2000 level of 11.7 quads, primary nuclear inputs increase at an average annual rate of 2.4 percent to a level of 21.1 quads in 2025. Non-fossil electric inputs increase to 12.2 quads and account for 7.2 percent of total primary resources by 2025.

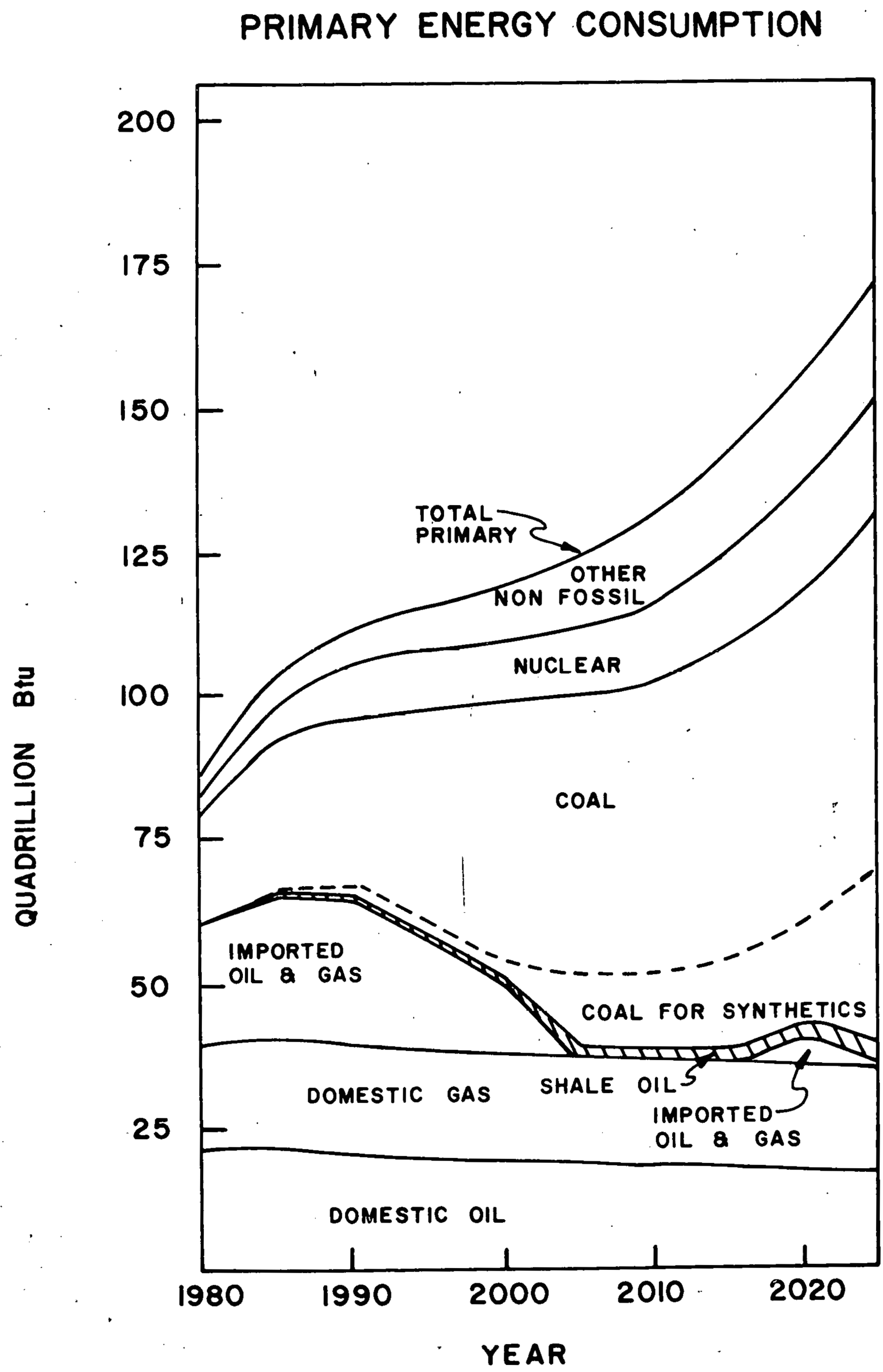

PRIMARY ENERGY CONSUMPTION
QUADRILLION Btu
200
175
150
125
100
75
50
25
TOTAL PRIMARY
OTHER NON FOSSIL
NUCLEAR
COAL
IMPORTED OIL & GAS
COAL FOR SYNTHETICS
SHALE OIL
IMPORTED OIL & GAS
DOMESTIC GAS
DOMESTIC OIL
1980
1990
2000
2010
2020
YEAR

Figure 23

Domestic oil and gas consumption levels continue to decline after 2000 and account for only 20.1 percent of total energy in 2025 as there occur substantial interfuel substitutions of direct coal use, synthetic fuels, and renewable resources for oil and gas by the end of the forecast period. However, the economy cannot fully maintain the energy import independence achieved during the 2000 to 2015 period and begins to import small quantities of oil and gas after the year 2015.

Electric Generation

Electricity generation grows from 7.2 quads in 1977 to 16.4 quads in 2000 and 25.0 quads in 2025. This corresponds to average annual growth of 3.6 percent and 1.7 percent in the pre- and post-2000 periods, respectively. Coal, nuclear, and non-fossil electric generation grow continuously over the projection period. The electrification of the energy system, as measured by the ratio of total electric inputs to total primary resources, grows from 29.9 percent in 1977 to 40.5 percent in 2000 and 42.4 percent in 2025.

Coal electric generation (including wood) increases its share of total generation from 46.7 percent in 1977 to 56.8 percent in 2000. Several advanced coal electric technologies appear by the year 2000. These include coal-combined cycle; coal, fluidized bed combustion (with and without cogeneration); and coal-steam systems, combined with cogeneration and district heating. These advanced coal-electric technologies use 24.3 percent of the coal burned for electric generation in 2000. By 2025, coal's share of total electric generation declines slightly to 54.2 percent as nuclear and non-fossil electric generation grows in importance. The advanced, coal-electric technologies consume 54.6 percent of the coal used for electric generation in 2025. Wood inputs to electric generation grow to 0.7 quads in 2000 and remain at that level through 2025. The share of oil and gas electric generation declines from 31.3 percent in 1977 to 3.7 percent in 2000 as coal, nuclear, and non-fossil generation increase. Gas generating capacity is phased-out completely by 2020, and oil follows by 2025. The share of nuclear electric generation in the form of light water reactors grows from 11.7 percent in 1977 to 24.6 percent in 2000 and 29.1 percent in 2025. This share represents a growth in nuclear generating capacity of 7.0 percent in the pre-2000 period and 3.4 percent in the post-2000 period. Non-fossil electric generation accounts for 14.9 percent of total generation in 2000 and 16.7 percent in 2025. Low head hydro, solar, and wind generation grow at the EIA/ARC specified rates.

Non-electric Advanced Supply Technologies

Solar for heating uses is projected to enter the system in 1980 at 0.02 quads and grows at an annual rate of 23.4 percent to 1.4 quads in 2000. In the post 2000 period, direct solar use grows at 3.4 percent per year to 3.1 quads in 2025. Solar, thermal electric generation grows at EIA/ARC specified levels in all years. Wood usage for heating provides 0.05 quads in 1980 and grows to 0.9 quads in 2000, an annual rate of 15.7 percent. After 2000 wood usage grows at 4.6 percent per year to a level of 2.8 quads in 2025. Wood (biomass) electric generation was fixed at the EIA/ARC specified level through 2000 and remains constant at 0.7 quads thereafter. Geothermal, industrial process heating becomes available in 1985 at 0.1 quads, grows to 0.6 quads by the year 2000 and 1.5 quads by 2025, growing annually at rates of 14.1 percent and 3.4 percent in the pre- and post-2000 periods, respectively. Wind electric systems provide 0.02 quads of primary equivalent energy in 1990, 0.85 quads in 2000, and 3.2 quads in 2025.

Shale oil production grows from 0.1 quads in 1980 to 1.0 quads in 2000 and 3.0 quads in 2025. High-Btu gas from coal penetrates the system at 0.08 quads in 1985 and stays at that level through 2000. After 2000, high-Btu gas availability grows at 10.5 percent per year to 1.0 quads in 2025. Methanol production starts at 0.07 quads per year in 1990 and grows at an annual rate of 33.7 percent to 1.3 quads in 2000. After 2000 an annual growth rate of 6.9 percent brings methanol production to 6.7 quads in 2025. Medium-Btu coal gas grows from 0.4 quads in 1990 to 1.3 quads in 2000 and 3.15 quads in 2025. These levels reflect annual growth rates of 12.0 percent and 3.5 percent in the pre- and post-2000 periods, respectively.

While some of the advanced technologies in the BNL/DJA projection were fixed in accordance with the EIA/ARC specified penetrations, others, most notably the synthetic fuels, were bounded only by the EIA/ARC limits and did not enter at these levels. The TESOM component of the BNL/DJA system incorporates a market penetration algorithm that takes as inputs optimistic penetration levels for each technology. Then, in each period, TESOM calculates a new upper bound from the input penetration level and the actual penetration level in the previous period. The accompanying table shows the effect of this algorithm on the penetration limits for coal liquids. TESOM calculates upper bounds for coal liquids which are consistently lower than the input bounds. In 2005, coal liquids become economic and enter the system. In 2010 the calculated bound is increased significantly.

COAL LIQUID PENETRATION LEVELS AND BOUNDS IN TESOM

Year	Input* Optimistic Penetration Level (quads)	TESOM Calculated Upper Bound (quads)	Output Level (quads)
1980	0.00	0.00	0.00
1985	0.07	0.06	0.00
1990	0.26	0.19	0.00
1995	0.92	0.63	0.00
2000	3.68	2.63	0.00
2005	7.40	3.54	2.63
2010	13.50	8.44	2.63
2015	14.00	3.11	2.65
2020	15.00	3.60	3.60
2025	21.00	9.54	9.54

*EIA/ARC specified levels, except in 2025.

However, the system does not require an increase in the use of liquids over the previous period; so in 2015 the calculated bound is lower, given the units put in place during the previous period. After 2015 as the output levels grow, the calculated bounds are raised. This penetration algorithm takes into account the marginal values, implementation rates, and lag times from previous periods, as well as the technological and market characteristics for the current period in determining more realistic bounds for the activity levels.

Demand Analysis

In the energy model component of the BNL/DJA system, the degree of technological detail represented for energy supply and conversion is extended to the demand side. Thus, energy services (e.g., space conditioning, process heat, motive power, etc.) are provided by a comprehensive set of end-use technologies. Over the period 1977 to 2025 wood-burning technologies, the heat pump, integrated solar systems, and heat from combined electric generating and district heating facilities account for increasing amounts of the energy required for residential and commercial space conditioning and miscellaneous heat. As indicated by the accompanying table, these technologies provide only 0.06 quads of the 10.32 quads of energy inputs to residential and commercial space heating in the year 1980. However, this 0.6 percent share grows to 14.8 percent by the year 2000 and 35.1 percent by the year 2025. In the industrial sector the future technological mix for process heat includes solar, geothermal, wood, cogeneration, low (medium)-Btu gas, and coal fluidized bed combustion (FBC). The latter two technologies, introduced in the last decade of the century, become major components of the industrial technological mix by 2025. Indeed, they account for slightly over one-third of the 28.72 quads of delivered energy required for process heat. More significantly, the combination of these enumerated technologies provides 60.8 percent of these delivered energy inputs. In transportation automobiles powered by electricity and fueled by methanol are introduced into the system. By the year 2025 methanol production reaches 6.72 quads and provides 21.4 percent of the delivered energy to the transportation sector.

In addition to new technologies, the importance of other end-use technology considerations (turn-over rates, efficiency improvements, and substitutions) cannot be overemphasized in discussions of the energy system in the long run. As presented in the accompanying table, the changes in the energy aggregates (primary, delivered, and energy services) provide a number of measures of energy system efficiency and aggregate efficiency changes. For example, as energy prices rise over the period 1980 to 2000, the ratio of delivered energy output to primary energy input deteriorates. This results from the substitutions of electricity and coal-based synthetics in the fuel mix for delivered energy. However, aggregate energy services per unit of delivered energy show a marked improvement over the period with the net effect of improving the overall energy system efficiency (energy services per unit of primary energy). Again, this partially results from the substitution of electricity which has a relatively higher efficiency in end-use. In addition, there are not only significant improvements in the efficiencies of end-use technologies, as vintage stocks are replaced, but also efficiency gains attributable to the substitution of other non-electric end-use devices. Over the period 2000 to 2025, the trends are still in evidence at a moderated rate, despite dampened, energy price increases.

The Role of "New" Technologies in Various End-Uses
(Quadrillion Btu)

	1980	2000	2025
Space Heat			
Wood	0.02	0.62	1.98
Heat Pump	0.04	0.65	1.77
Solar	0.00	0.40	0.89
District Heating	0.00	0.08	0.37
Total	0.06	1.75	5.01
Total Energy Input to End-use	10.32	11.81	14.26
Process Heat			
Solar	0.01	0.62	1.38
Geothermal	0.00	0.65	1.50
Wood	0.04	0.19	0.59
Cogeneration (Heat)	0.00	1.31	4.39
Low (med.)-Btu Gas	0.00	1.34	3.15
Coal-FBC	0.00	0.40	6.46
Total	0.05	4.51	17.47
Total Energy Input to End-use	14.49	19.71	28.72
Motive Power			
Methanol	0.00	1.28	6.72
Total Energy Input to End-use	21.43	23.65	31.44

Aggregate Energy Quantities and System Efficiencies

	1980	Percent Change	2000	Percent Change	2025
Energy quantities (quads)					
I. Total primary energy	86.49	35.6	117.28	45.2	170.27
II. Total delivered energy	62.42	30.7	81.57	40.4	114.53
III. Total energy services	34.66	63.6	56.70	52.3	86.34
System efficiencies					
II./I.	.722	-3.6	.696	-3.3	.673
III./II.	.555	25.2	.695	8.3	.753
III./I.	.401	20.4	.483	5.0	.507

Primary Energy and Composition

Primary energy consumption in the LEAP model system is projected to reach 122.0 quads in 2000 and 166.9 quads in 2020. These levels reflect average annual growth rates of 2.1 percent from 1977 to 2000 and 1.6 percent from 2000 to 2020. The share of domestic oil, including shale oil, declines from 24.2 percent of total primary energy in 1977 to 9.1 percent in 2020. The share of domestic gas drops even more dramatically from 24.6 percent in 1977 to 6.8 percent in 2020. Over the course of the 1977-2020 period, aggregate oil and gas imports are reduced from 19.7 quads to 8.4 quads, an average annual rate of 2.0 percent.

Coal and nuclear fuel are the two primary energy sources that take over the bulk of the market. Coal consumption increases at a fast rate of 5.0 percent per annum from 1977 (14.1 quads) to 2000 (43.8 quads) and, thereafter, increases at 2.3 percent per annum to 2020 (74.5 quads). Even more significant is the growth in coal's share of total primary energy from 18.7 percent in 1977 to 35.9 percent in 2000 and 44.7 percent in 2020. Most of this growth can be attributed to the rapid development of coal-based synthetics after 1990. Nuclear energy's growth pattern is similar to that of coal. From an initial share of 3.5 percent (2.7 quads) of total primary energy in 1977, nuclear fuel's share grows to 13.8 percent (16.9 quads) in 2000 and 26.1 percent (43.56) in 2020. These levels translate to average, annual growth rates of 8.4 percent and 4.9 percent in the pre- and post-2000 periods, respectively. The use of other non-fossil sources of energy increases at an average annual rate of 3.2 percent over the 1977-2020 period. However, by 2020 these sources only account for 5.2 percent of total primary energy.

Electric Generation

Total electricity generation is projected to grow at an average rate of 3.9 percent per annum prior to 2000 and 2.3 percent per year during the 2000-2030 period. The amount of electricity generated increases from 7.2 quads in 1977 to 17.5 quads in 2000 and 27.7 quads in 2020. The electrification of the energy system grows from 29.9 percent in 1977 to 40.4 percent in 2000 and 47.8 percent in 2020. The share of coal-based generation rises from 46.4 percent of total electricity generation in 1977 to 56.5 percent in 1995. This share declines steadily thereafter to 41.0 percent in 2020 despite the growth of the coal-combined cycle, atmospheric fluidized bed, and magnetodynamic technologies during this period. Oil and gas fueled generation decreases sharply from a combined share of 31.2 percent in 1977 to 1.8 percent in 2020. The rapid expansion of nuclear powered generation, which grows from a 1977 share of 11.7 percent to 49.9 percent in 2020, is primarily responsible for the increase in the system's electrification. Almost all of the nuclear power is generated by LWR's with breeder reactors just beginning to enter the market (0.04 quads generated in 2020) after 2010. The share of other non-fossil based generation decreases over time, with the combined hydroelectric and geothermal generation remaining constant at 1.33 quads from 2000 on and the combined generation from solar thermal, ocean thermal, wind power, and biomass increasing only slightly from 0.26 quads in 2000 to 0.71 quads in 2020.

Non-electric Supply Side Advanced Technologies

Coal-based synthetic fuels play a very significant role in the LEAP scenario, functioning along with nuclear-powered electricity as the replacement for domestic and imported oil and natural gas. Overall, the synthetics first appear in 2000 at a level of 12.8 quads by 2000 over a ten year period and grow at an average rate of 4.47 per annum to 30.7 quads in 2020. Liquefaction plays an important role increasing from 2.6 quads produced in 2000 to 11.0 quads in 2020. High Btu coal gas enters the scenario but at a much lower level reaching 2.7 quads by the end of the time frame. Low and medium Btu gas represent important indirect uses of coal in combined cycle electrical generation.

Shale oil first appears in 1990 at 0.4 quads and increases steadily to 5.1 quads in 2020, a share of 3.0 percent of total primary energy. Although also exhibiting consistent growth after an initial level of 0.01 quads in 1985, direct use of non-fossil sources (solar and geothermal heating) does not play as significant a role, ultimately capturing a 1.6 percent share of total primary energy in 2020.

Demand Side Analysis

Information was supplied on the mix of fuels within three demand sectors: residential/commercial, industrial, and transportation. Over all sectors, delivered energy increases from 60.9 quads in 1980 to 104.3 quads in 2020, which corresponds to an average, annual growth rate of 1.4 percent. However, of the three sectors only the industrial sector exhibits a steady increase in the level of delivered energy. Within this sector delivered coal displays the most significant growth from a market share of 17.4 percent in 1980

LEAP MODELING SYSTEM
PRIMARY ENERGY CONSUMPTION

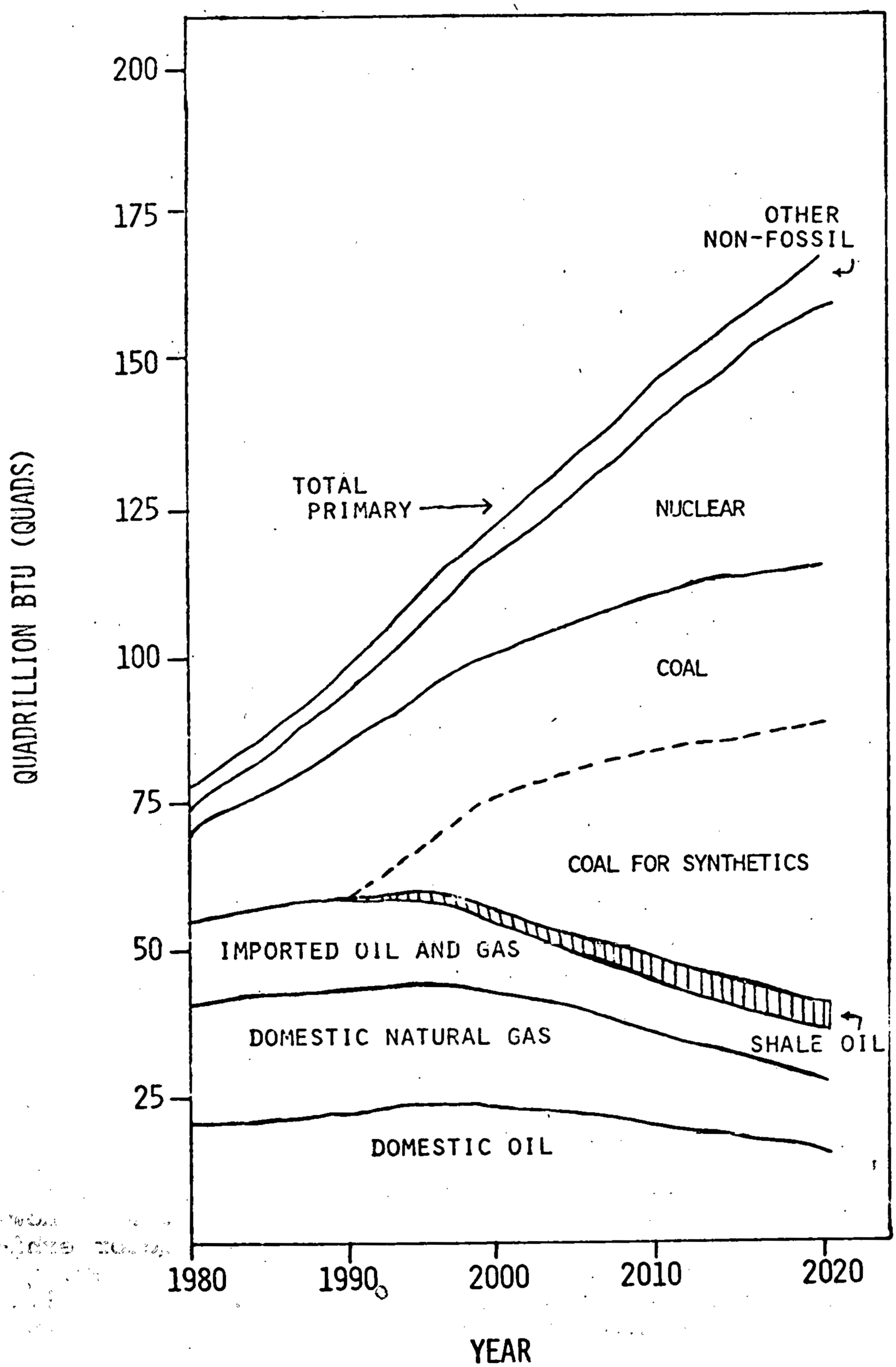


Figure 24

to 40.5 percent in 2020.Although delivered oil to industry increases over this time period, the market share falls from 34.1 to 24.9 percent. The market share of natural gas declines even more from 36.5 in 1980 to 13.8 in 2020. Along with a change to coal, industrial switching to electricity occurs with a level of 2.7 quads delivered (11.4 percent share) in 1980 increasing to 12.3 quads (19.7 percent share) in 2020. Direct heat (solar, geothermal, by-product, and cogeneration) also functions, after 1990, as a substitute for oil and gas but on a much more restricted level (1.3 quads in 2020). The level of delivered energy to the residential/ commercial sector fluctuates slightly up and down from 1980 to 2020 and shows only modest growth from 18.7 to 20.1 quads over the time period. Oil and gas, with a combined market share of 75.4 percent in 1980 dropping to 34.1 percent in 2020, are replaced primarily by electricity. Solar and by-product heating enter in 2000 but together only capture 3.3 percent of the market by 2020. Delivered energy levels to the transporation sector also fluctuate over time between a minimum of 18.5 quads in 1980 and a maximum of 22.3 quads in 2010. Oil products account for almost all of this with a small, relatively constant contribution from natural gas (between 2.5 and 3.5 percent share).

INTERMODEL COMPARISON OF RESULTS

Preliminary Remarks

In the previous section brief descriptions of the projections from each model system were presented. In this section we relate the diferences in the model results to the diverse structural features of each model and the influences which these exert on their respective projections. By comparing the projections, investigative issues are raised concerning the comparative behavior of the models in response to what is, presumably, a common set of underlying assumptions. The comparative results are interpreted in terms of the insights which they provide into the prospects or potential problems envisioned for the energy system over the long-run.

Energy-GNP Ratios

The demand for energy largely results from the demand for other non-energy goods and services. For example, consumers do not demand energy specifically, but do demand heat, air conditioning, mechanical drive, and transportation. Similarly in industry the predominant demand is for energy services such as steam, process heat, mechanical drive, and electrolytic reduction.

A common measure of the aggregate efficiency of energy use in the economy is provided by the ratio of primary energy consumption to the constant dollar value of total final output (i.e., the GNP). While fluctuating both upward and downward in the short-run, there has been a general downward trend in this measure over the last thirty years. This has occurred even though delivered energy prices were declining for much of this period in real terms. Under conditions of rising real energy prices, the expectation is that the energy intensity of the economy should continue to decline given increases in the technical efficiencies of energy conversion and end-use, technical progress throughout the economy, and shifts in spending and production patterns away from energy.

A fully endogenous energy-economy linkage is contained only in the BNL/DJA model. The specific energy components of all five models are quite similar in their capability to substitute fuels and reflect technological change. The degree to which the models represent energy service demands differs, however. FOSSIL2 and ETA-MACRO incorporate little or no substitution, while PILOT/WEM, LEAP, and BNL/DJA capture many more such possibilities. Only PILOT/WEM, ETA-MACRO, and BNL/DJA couple the price of energy or energy services back to an economic model to affect GNP growth. Finally, only the DJA component modifies sectoral factor demands endogenously in response to changes in relative prices or other variables.

The energy-GNP ratios from the projections developed for the ARC are presented in the accompanying table and graph. The FOSSIL2 and LEAP models show a continuous decline in the energy-GNP ratio over the period 1980 to 2020. However, this outcome is only partially endogenous to these projections. FOSSIL2 and LEAP begin with exogenously specified GNP trajectories which serve to drive energy demand. As real energy prices rise, there are dampening repercussions on the growth of energy demand as well as the initial specification of the trend in GNP. The GNP projection was provided by the Data Resources, Incorporated (DRI) Macroeconomic Model which, in turn, focuses primarily on the long-run trends in final spending patterns and aggregate demand behavior. It is the combination of the exogenous GNP projection and the endogenous downward adjustments to GNP and energy demand, as energy prices rise, that leads to the projected decline in the FOSSIL2 energy-GNP ratio.

LEAP did not vary GNP growth as a function of energy price and so the decline in energy-GNP growth is a function of the energy price elasticity only.

A noticeable feature of the trend in the energy-GNP ratio from the PILOT projection is its similarity to the results obtained from FOSSIL2 after 1980. The two trend lines are intertwined throughout the entire period after 1980, common to the two projections. Of interest, however, is that much of the energy-economy interaction for FOSSIL2 is implicit in the exogenous GNP projection whereas, in PILOT, the level of output and energy/non-energy price and quantity adjustments are endogenous. The PPIM/WEM formulation employs a hierarchy of substitution functions for the producing sectors of the economy and a detailed process representation for the consumers. Given the exogenous inputs and both exogenous and endogenous changes in relative prices, the energy and economic systems move to and then along a new equilibrium path. The adjustment process in the producing sectors is characterized by only one class of interactions as the components of this hierarchy of functions permit only pair-wise substitution at each decision level. This specification eliminates the possibility of complementarity between input pairs in the producing sectors. Hence, the long-run, dynamic effects of energy changes on producing sectors of the economy are similar to those provided in ETA-MACRO and underlying the results of FOSSIL2.

The ETA-MACRO model was run under three different assumptions concerning the elasticity of substitution (ESUB) of non-energy for energy inputs into the production of final output. The three values result in a slightly different energy price trajectory for each elasticity assumption. For a given set of energy price increases, the higher the elasticity, the easier it is to substitute for energy and the lesser is the effect of the energy reductions on GNP. For any year, given the differing energy prices, the ETA-MACRO model predicts a lower, total, primary energy consumption and a higher GNP as the elasticity of substitution is increased. Consequently, the energy-GNP ratio is lower. To the year 2000 and for the derived energy price changes, the energy-GNP ratio declines; this decline is accelerated the higher the elasticity of substitution. After the year 2000, there is an endogenous stabilization of real energy prices despite the increases in the costs of imported oil and gas. In part, this is attributable to the availability of a backstop for these fuels at a roughly constant price over the remainder of the time horizon. This price stability contributes to the relatively accelerated growth of aggregate energy demand from 2000 to 2030. Further, there are continued increases in electrification and synfuels production which lead to higher Btu input contents per unit output of useful energy. These further explain the increased growth of primary energy over the post-2000 period. However, it is more difficult to explain the reversals or shifts toward the constancy of the long-run, energy-GNP ratio. These changes cannot be explained by a "putty-clay" relationship between factor inputs and total output as, presumably, the post-1970 vintages of capital in ETA-MARCO become more energy efficient over time under any of the elasticity assumptions. The combination of the elasticity of substitution magnitude and the "putty-clay" assumption regarding the input requirements for aggregate production, govern only the relative positions of the energy-GNP ratio trend lines. It is the changes in relative factor prices (energy and non-energy) that govern the temporal behavior of the ratio for a given elasticity assumption and, herein, lies the explanation for the relatively stable behavior of the ratio after 2000. It is the case that the MACRO component of ETA-MACRO is based on an aggregate production function in four inputs--capital, labor, electric energy, and non-electric energy. Separability is imposed on the function forming two subaggregate inputs--aggregate energy and an aggregate capital labor input. Further, Harrod-neutral technological change is introduced into the function by describing labor inputs in terms of efficiency units. This assertion means that if energy prices remain roughly constant and if energy and capital increase at approximately the same rate as the labor force index, then gross output also increases at approximately this rate. At constant energy prices, the combination of the separability assumption, Harrod-neutrality, and a constant elasticity of substitution between the two subaggregates insures that capital, labor, energy, and output grow at the same rate. Hence, it is the specification of the production function, the relative stability of energy prices, and the exogenous growth in labor efficiency units that explain the constancy of the energy-GNP ratio.

The trend line for the energy-GNP ratio from the BNL/DJA model system behaves quite differently from the results obtained from the other models. In the early years to 1985, real energy price changes are relatively small, as natural gas prices are deregulated gradually and decontrol permits domestic oil prices to rise to a constant real world oil price. These price changes combined with the relative inability to adjust instantaneously energy-producing and consuming capital stocks result in the apparent constancy of the ratio. After 1985, when energy prices exhibit more rapid upward movement and constraints on capital stock turnover become less restrictive, the energy-GNP ratio follows the downward trend predicted by the other models. However, this decline begins from a relatively larger value. Thus, except for the ETA-MACRO ESUB=.20 projection, the BNL/DJA trend line lies above the other estimates to approximately the year 1995. After this time, the BNL/DJA ratio continues its downward trend but at a slower rate of descent as energy price increases are moderated and other energy-economy interactions dominate the projection. From approximately 2000 to the year 2025, the BNL/DNA ratio lies below those of the other reference estimates and approaches that of the ETA-MACRO ESUB=.50 projection. The pattern of the energy-GNP ratio from the BNL/DJA projection suggests that the ability of the energy and economic systems to adjust to higher energy prices is temporally variable with the degree of responsiveness being relatively larger in the long-run than in the short-run. The reductions in the level of energy use and the redirection of the structure of that use, induced by higher energy prices, are related closely to temporal changes in the level and patterns of economic activity. Similarly, changes in the patterns of energy supply and conversion are related closely to changes in the underlying economic and technological conditions affecting the energy sector. The hierarchy of submodels for consumption and for each of the producing sectors (energy and non-energy alike) incorporates the patterns of behavioral and technical responses observed or attainable for these activities. The endogenous input-output coefficients and pattern of household spending are modeled in a flexible manner and provide for both substitution and complementarity relationships between inputs and products. The changes in final demand spending and production input patterns allow the price-induced, energy reductions to be achieved without a comparable reduction in the level of economic activity. With prices determined to clear all markets, the changes in expenditure patterns have implications for rates of return, the rate of growth of factor productivities, endogenous technical progress, investment (saving) behavior and its effect on capital formation and, thus, economic growth. The endogenous dynamic effects which are the direct result of the substitution and complementarity relationships exert increasing influence on the energy intensity of aggregate production. These cumulative temporal influences are illustrated by the departure from the reference energy-GNP ratio projections of the other models in the BNL/DJA trend.

In the context of the reference projections from the various models, the question arises as to the extent these structural characteristics influence the resulting prediction of the energy-GNP ratio. The answer appears mixed. For the pre-2000 period some of the differing methodologies provide quite similar estimates of the magnitude of and trend in the energy-GNP ratio. This is largely the result of the inherent inertia of the energy-utilizing capital stock captured by these models. The differences that do exist are explained by the alternative dynamic representations contained in each of the models. However, after 2000, there is a marked divergence in the reference projections for this measure. Such a divergence might be more easily dismissed if the period 1995 and beyond was not crucial to technological change in the energy system. Although the energy-GNP ratio is only one indicator of the role of energy in the economy, these post-2000 results cannot justifiably be attributed to either the presumed inability of the models to predict the future or the acknowledged uncertainty which characterizes the long-run planning horizon. Clearly, it is the intrinsic dynamic properties of these model systems which provide this divergence and it is these properties which merit rigorous investigation if such models and their projections are to be usefully applied.

ENERGY - GNP RATIOS

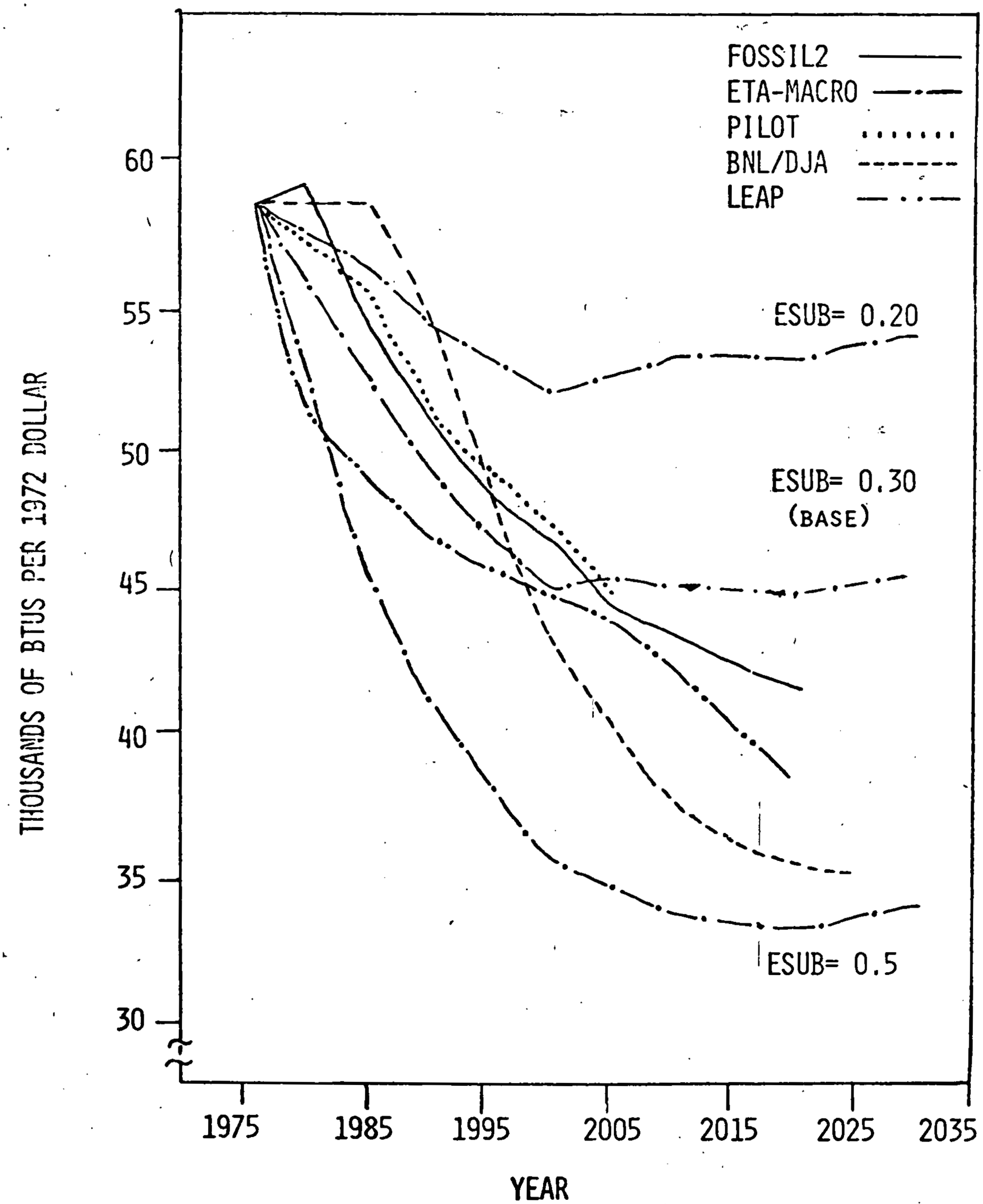


Figure 25

ENERGY-GNP RATIOS*
(Thousands of Btus per 1972 Dollar)

YEAR	FOSSIL2	PILOT	ETA - MACRO** ESUB= .20	ESUB= .30	ESUB= .50	BNL/DJA	LEAP
1980	60.1	57.1	--	--	--	--	51.5
1985	55.1	55.3	56.2	52.3	45.7	58.5	48.8
1990	51.5	51.1	54.1	49.3	41.2	54.5	47.1
1995	48.9	49.0	--	46.8	--	48.8	45.9
2000	46.2	47.2	51.9	45.1	35.8	43.3	45.0
2005	44.6	44.7	--	--	--	40.6	43.8
2010	43.2	--	53.1	45.1	33.9	37.6	42.4
2015	42.2	--	--	--	--	36.2	40.4
2020	40.9	--	53.0	44.8	33.3	35.4	38.3
2025	--	--	--	--	--	35.0	--
2030	--	--	53.9	46.1	34.1	--	

*The actual Energy-GNP Ratio in 1976 was 58.4 thousands of Btus for each 1972 dollar of final output.

**The ESUB parameter in ETA-MACRO is an exogenously-specified elasticity of substitution between energy and non-energy factors of production. The reference projection for ETA-MACRO is that represented by the elasticity of 0.30. Results are not directly comparable as each specification reflects slightly different energy prices.

Primary Energy

In the pre-2000, period FOSSIL2, ETA-MACRO, and LEAP consistently project total primary energy consumption levels below those of PILOT and BNL/DJA. However, by the year 2000, the BNL/DJA projection falls below all of the others and maintains this relative position throughout the remaining forecast period. The ETA-MACRO projection coincides with the PILOT projection of total, primary energy consumption in 2005 (the last year PPIM/WEM projection results are provided) and continues to yield the highest levels of primary energy consumption through the rest of the time frame. While all of the models project increasing levels of primary energy consumption over time, the rate of growth slows significantly in the post-2000 period for all of the projections except ETA-MACRO.

In all of the projections the nuclear energy usage increases throughout the time frame but shows greatest growth in the ETA-MACRO projection, particularly after 2000. Domestic oil and gas usage and production decline constantly in all of the projections. Imports of oil and gas disappear by 2015 in ETA-MACRO and by 2005 in BNL/DJA. However, they reappear in the BNL/DJA projection for 2020 and 2025 as the endogenous growth projected for the synfuel industries is insufficient to maintain energy "independence." Energy imports continue to play an important role to 2020 in FOSSIL2 and 2005, the final time period, in PILOT, and in FOSSIL2 there is an increase in oil imports from 2000 to 2020 in FOSSIL2.

Coal is projected to become the dominant fuel by playing an increasingly important role over the entire time horizon for electric generation, direct use, and synthetic fuel production. All of the model systems excepting PPIM/WEM project the rate of coal utilization to increase after the year 2000. This is largely due to the increased requirements for synthetic fuels to alleviate the persistent liquids problem. ETA-MACRO, FOSSIL2, and LEAP project rather smooth growth paths for coal use. BNL/DJA's trajectory is somewhat different, with a rapid increase occurring in the 2000-2005 period as synfuel production grows rapidly, a slowing of growth from 2005 to 2020 as the synfuel production responds to the market expansion limits calculated in TESOM, and a rapid increase again after 2020 as these penetration levels become less constraining due to the increased attractiveness of the industry. Other non-fossil primary energy forms grow similarly in all of the projections as most of the models adhered to the EIA/ARC guidelines on implementation levels for these technologies. Direct comparison in this category of ETA-MACRO with the other models cannot be made because of the presence of the unspecified backstop technology (AES). The importance of liquid and gaseous fuels over the long-run is evident in all of the projections. The combined use of conventional oil and gas and shale oil decreases over time. However, increasing amounts of coal for synthetic fuels production is projected by all of the models. The usage of primary energy resources for producing liquids and gaseous fuels increases continually in FOSSIL2, PILOT/WEM, and LEAP; usage increases to about 2005 in ETA-MACRO, then decreases to 2015 and rises again thereafter; usage increases to 1990 in the BNL/DJA projection, then decreases to 2000 and rises continually to 2025. In both ETA-MACRO and BNL/DJA, unlike the other projections, primary resources providing liquids and gases decline during a phase of the time horizon but return to approximately their 1990 levels by the year 2025. However, use of the backstop technology in ETA-MACRO increases rapidly in the post-2000 period. This backstop, being unspecified in nature, could be contributing to or displacing liquids and gases in the system.

CROSS MODEL COMPARISON

DOMESTIC PRIMARY ENERGY USAGE
(Quadrillion Btu)

YEAR	FOSSIL2	PILOT/WEM	ETA/MACRO	BNL/DJA	LEAP
1980	86	87	81	86	78
1985	92	98	91	104	88
1990	101	106	101	112	98
1995	110	119	110	115	111
2000	119	129	121	117	122
2005	131	138	138	125	134
2010	142	-	153	130	146
2015	154	-	166	141	156
2020	164	-	186	154	167
2025	-	-	206	170	

CROSS MODEL COMPARISON

TOTAL PRIMARY RESOURCE CONSUMPTION

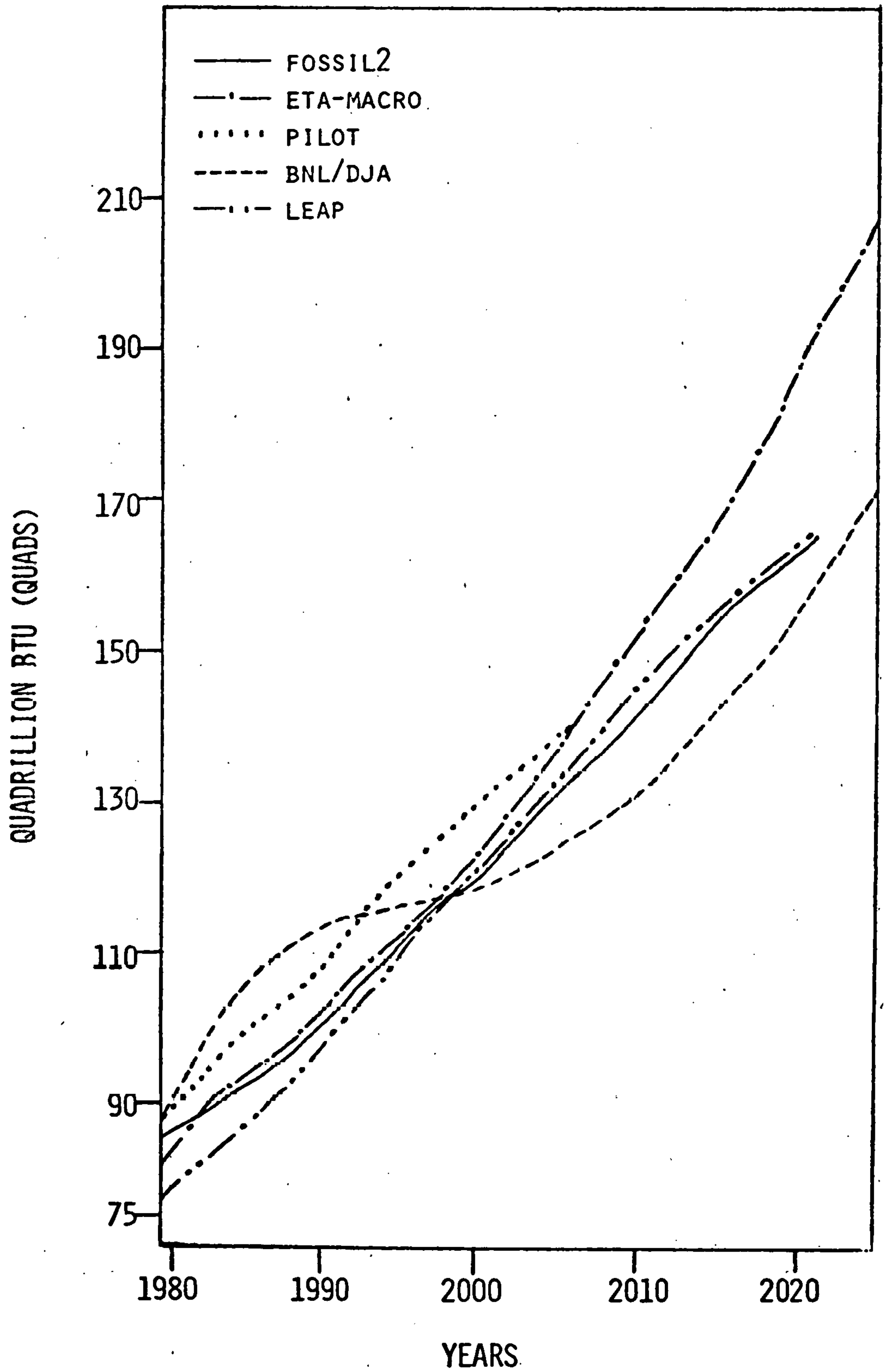


Figure 26

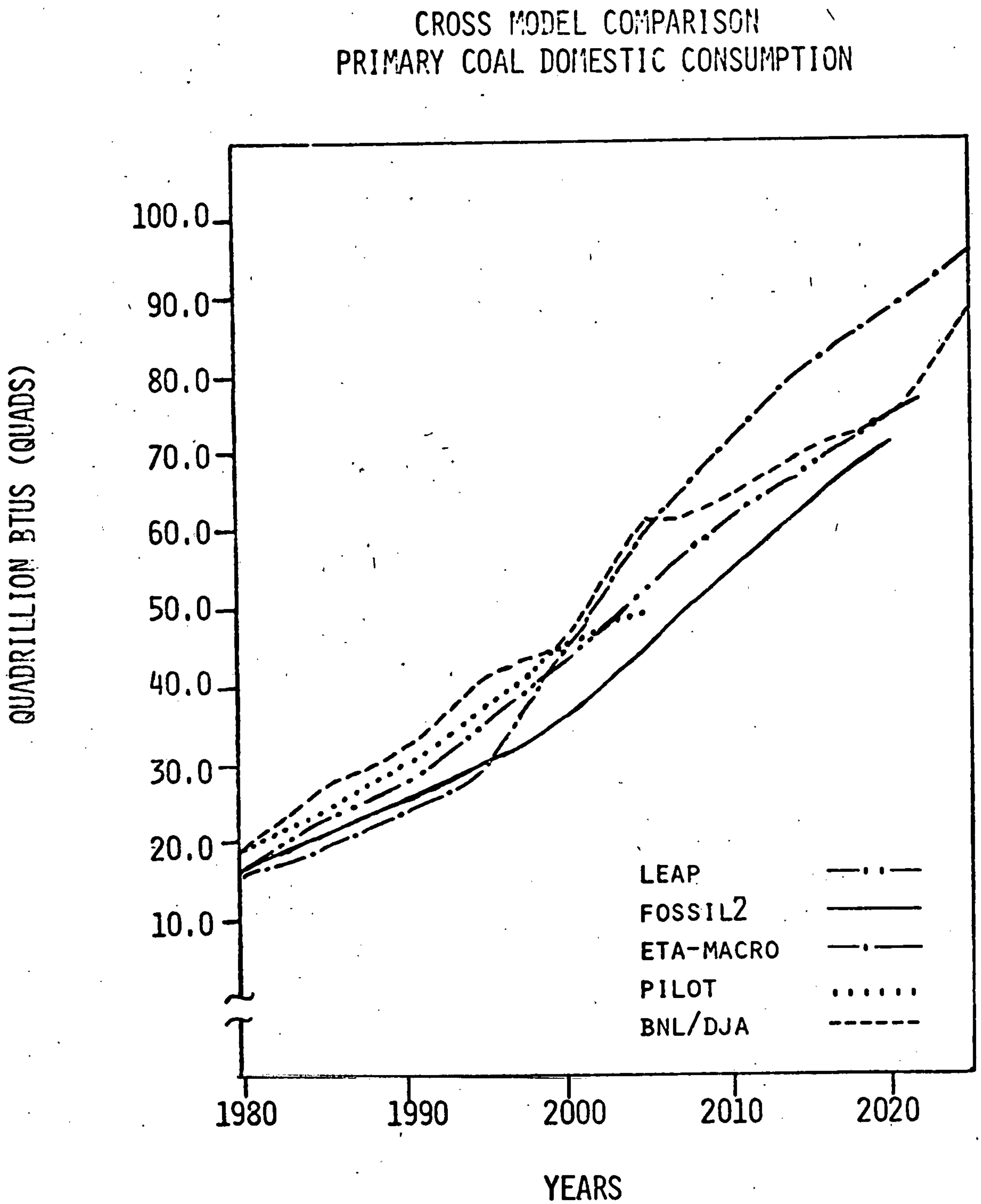

CROSS MODEL COMPARISON
PRIMARY COAL DOMESTIC CONSUMPTION
QUADRILLION BTUS (QUADS)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
LEAP
FOSSIL2
ETA-MACRO
PILOT
BNL/DJA
1980
1990
2000
2010
2020
YEARS

Figure 27

Role of Alternative Electric Generation Technologies

The intermodel comparison of electric generation demonstrates basic qualitative agreement among all four participating model systems. The magnitudes of electric generation and market shares differ, reflecting differences in the magnitude of the energy-economy interactions and differing model structures. Several consistent trends for electrification can be derived from all of the projections:

- The energy system is moving toward electrification over the entire time horizon. The rate is faster for the pre-2000 period than for the post-2000 period. This rate partially reflects the more rapid increases in the pre-2000 period of oil costs and consequent retirement or reduction to cycling plants of oil steam electric generation plants than in the post-2000 period. Electrification, measured by the ratio of inputs to electricity generating plants versus total primary energy, is projected to be between 40 and 50 percent by the year 2020.

- Nuclear plants show the most rapid increase capturing at least 25 percent of the electric generation market by the year 2000. The market share for nuclear electricity is lowest for the BNL/DJA system reflecting limitations placed on nuclear generation stock for electric generation.

- All models project that electric, coal conversion technologies will continue to play a dominant role in the energy system with conventional coal steam electric showing continued growth to approximately 1995 when the advanced coal technologies (e.g., fluidized bed combustion, district heating) slow, and eventually stop, the growth of conventional coal steam electric plants.

- Advanced non-fossil electric generation technologies (e.g., solar thermal, fast-breeder) make minor impacts on the overall system since they usually account for less than one percent of the total generation capacity.

The precise mix and timing of electric generation technologies for each model depends primarily on the mathematical construct of the model. Those which know and fully utilize the first date of availability of new technologies in the future and the price/quantity trajectories of fuels (e.g., PILOT, ETA-MACRO, LEAP) show a more rapid transition to advanced coal-based and nuclear technologies than those which exhibit simulation qualitites (FOSSIL2, BNL/DJA). The degree of electrification for the ETA-MACRO and PILOT models is at a lower level than for FOSSIL2 or BNL/DJA for the pre-1995 period. In ETA-MACRO stock in place in 1970 is retired at 4 percent per year and dominates the solution behavior through 1995. For PILOT all installed capacities may be retired prior to the end of their economic life. In general, installed capacity in the LEAP model cannot be effectively retired. In both of these dynamic models, the mix of generation technologies is partially influenced by the initial stock being economically competitive. .TESOM (BNL/DJA), like PILOT, permits premature retirement of installed capacity if the objective warrants it as does FOSSIL2. One major modeling difference which influences the quantity of capacity installed is the way in which load duration characteristics of demands are incorporated within each model structure. Only LEAP and the BNL/DJA model system incorporate load duration characteristics. This affects the mix, time of installation, and use (e.g., baseload, peaking) of the conversion devices.

The price of delivered electricity shows very little consistency across models. FOSSIL2 projects a smoothly increasing electric price trajectory reflecting the characteristics embodied in the slow retirement of oil steam electric plants. The price is later moderated by the increasing share of nuclear and other coal-based advanced technologies.

The price behavior for ETA-MACRO and PILOT/WEM is attributable to the combination of inherited central station stock which cannot be retired and the model structures which incorporate knowledge of future resource availabilities and price/quantity relationships which act to eventually reduce the average delivered price of electricity and later stabilize it.

The cyclic electric price behavior for the BNL/DJA model system can be accounted for as follows. The investments for oil steam electric plants in the early periods and the escalating oil and gas prices account for the first increasing segment to 1990. The retirement of older oil and gas burning vintage stock and replacement with more efficient coal burning technologies and increased nuclear generation act to reduce the price of delivered electricity through year 2005. The second increasing cost segment arises with the forced introduction of advanced, costly, electric generation devices coupled with rising resource prices.

The LEAP model has a farsighted and general energy equilibrium structure that is unique among the five models in the study. The smooth and very gradual increase in the delivered price of electricity exhibited in the model can be attributed to this structure and the mode of high sensitivity to price changes under which the scenario was run.

CROSS MODEL COMPARISON
ELECTRIC GENERATION

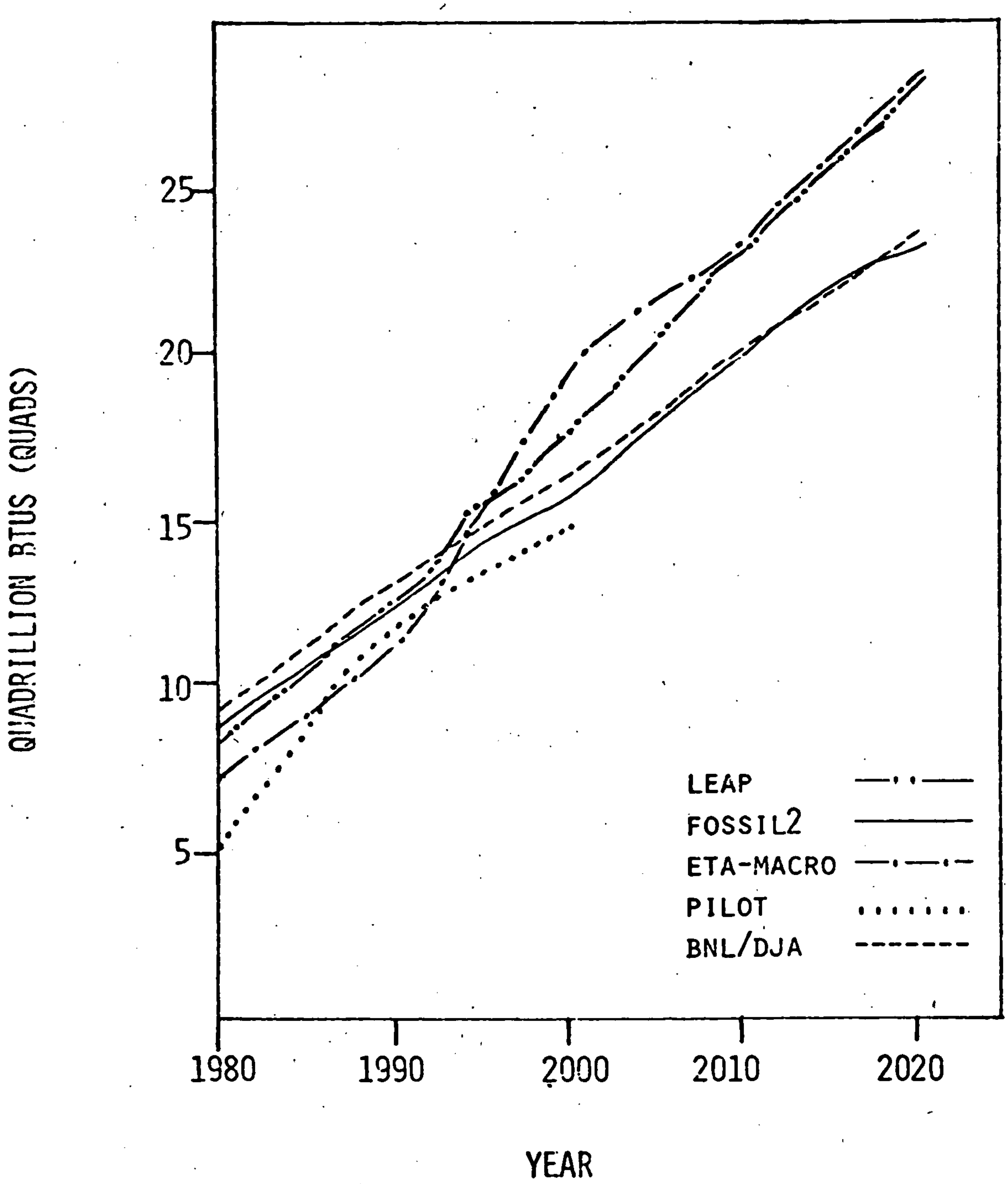


Figure 28

Electric Generation, 1990
(Quadrillion Btu)

	PILOT	FOSSIL2	BNL/DJA	ETA-MACRO	LEAP
Total Coal	6.63	5.8	7.49[a]	5.28	6.91
Conventional Coal	6.63		7.40[a]	5.07	
Coal Combined Cycle			0.08	0.21	
Coal FBC					
Coal Steam/DH					
Coal Combined Cycle/DH			0.03		
Coal FBC/COG			0.07		
Other Coal Electric					
Total Oil	1.01[b]	1.7	0.59	1.10[c]	0.63
Oil Steam			0.52		
Oil Combined Cycle					
Oil-Coal Steam					
Gas Turbine					
Total Energy System			0.07		
Oil Steam/DH					
Oil Combined Cycle/DH					
Oil Steam/COG					
Gas Turbine/COG					
Fuel Cell					
Other Oil Electric					

[a]Includes electricity generated by burning wood in coal steam plants.
[b]Includes all advanced non-fossil sources of electricity except solar.
[c]Includes both oil and natural gas sources of electricity.

Electric Generation, 1990 (Cont.)
(Quadrillion Btu)

	PILOT	FOSSIL2	BNL/DJA	ETA-MACRO	LEAP
Total Gas		0.5	0.47		0.84
Gas Steam			0.47		
Gas Turbine					
Total Enegy System					
Gas Steam/DH					
Gas Steam/COG					
Gas Turbine/COG					
Fuel Cell					
Other Gas Electric					
Total Nuclear	2.91	3.0	3.12	2.67	2.7
LWR	2.91		3.12	2.67	
LMFBR					
Other Nuclear Electric					
Hydroelectric and Geothermal	1.06	1.2	1.51	1.87	1.23
Solar Electric			0.01		
Other Non-Fossil Electric			0.01		
Wind Energy System			0.01		
Photovoltaic					
Ocean Thermal					
Biomass Electric					
Other Non-Fossil					
Total Electric Generation	11.61	12.2	13.10	10.92	12.3

Electric Generation, 2000
(Quadrillion Btu)

	PILOT	FOSSIL2	BNL/DJA	ETA-MACRO	LEAP
Total Coal	8.28	7.5	9.31[a]	7.60	9.40
Conventional Coal	8.28	6.1	7.20[a]	5.50	5.80
Coal Combined Cycle		1.1	0.85	2.10	2.70
Coal FBC		0.3	0.27		0.90
Coal Steam/DH			0.26		
Coal Combined Cycle/DH					
Coal FBC/DH					
Coal Steam/COG			0.46		
Coal FBC/COG			0.27		
Other Coal Electric					
Total Oil	0.72[b]	1.3	0.37	.37[c]	0.44
Oil Steam			0.31		0.40
Oil Combined Cycle					
Oil-Coal Steam					
Gas Turbine			0.06		0.01
Total Energy System					
Oil Steam/DH					
Oil Combined Cycle/DH					
Oil Steam/COG					
Gas Turbine/COG					0.02
Fuel Cell					
Other Oil Electric					

[a] Includes electricity generated by burning wood in coal steam plants.
[b] Includes all advanced non-fossil sources of electricity except solar.
[c] Includes both oil and natural gas sources of electricity.

Electric Generation, 2000 (Cont.)
(Quadrillion Btu)

	PILOT	FOSSIL2	BNL/DJA	ETA-MACRO	LEAP
Total Gas		0.2	0.23		0.64
Gas Steam			0.23		0.50
Gas Turbine					0.14
Total Enegy System					
Gas Steam/DH					
Gas Steam/COG					
Gas Turbine/COG					
Fuel Cell					
Other Gas Electric					
Total Nuclear	4.37	5.0	4.03	4.27	5.3
LWR	4.37	5.0	4.03	4.27	5.3
LMFBR					
Other Nuclear Electric					
Hydroelectric and Geothermal	1.09	1.4	1.74	2.39	1.33
Solar Electric	0.05	0.03	0.25		
Other Non-Fossil Electric		0.13	0.30		0.26[a]
Wind Energy System		0.03	0.30		
Photovoltaic					
Ocean Thermal					
Biomass Electric		0.1			
Other Non-Fossil					
Total Electric Generation	14.51	15.56	16.23	14.63	17.77

[a]Includes solar thermal.

Electric Generation, 2010
(Quadrillion Btu)

	PILOT	FOSSIL2	BNL/DJA	ETA-MACRO	LEAP
Total Coal		10.0	11.59[a]	11.10	11.00
Conventional Coal		6.3	4.47[a]	4.85	5.20
Coal Combined Cycle		3.2	3.00	6.25	3.50
Coal FBC		0.6	1.02		1.20
Coal Steam/DH			0.51		
Coal Combined Cycle/DH					
Coal FBC/DH					
Coal Steam/COG			1.57		
Coal FBC/COG			1.02		
Other Coal Electric					1.10
Total Oil		1.1	0.21	0.0	0.24
Oil Steam			0.17		0.20
Oil Combined Cycle					
Oil-Coal Steam					
Gas Turbine			0.04		0.02
Total Energy System					
Oil Steam/DH					
Oil Combined Cycle/DH					
Oil Steam/COG					
Gas Turbine/COG					
Fuel Cell					0.02
Other Oil Electric					

[a]Includes electricity generated by burning wood in coal steam plants.

Electric Generation, 2010 (Cont.)
(Quadrillion Btu)

	PILOT	FOSSIL2	BNL/DJA	ETA-MACRO	LEAP
Total Gas		0.1	0.12	0.0	0.45
Gas Steam			0.12		0.30
Gas Turbine					0.15
Total Enegy System					
Gas Steam/DH					
Gas Steam/COG					
Gas Turbine/COG					
Fuel Cell					
Other Gas Electric					
Total Nuclear		6.8	4.87	9.71	9.21
LWR		6.8	4.87	9.71	9.20
LMFBR					
Other Nuclear Electric					
Hydroelectric and Geothermal		1.5	1.79	2.39	1.33
Solar Electric		0.1	0.56	0.0	
Other Non-Fossil Electric		0.3	1.05		0.44[a]
Wind Energy System		0.2	1.05		
Photovoltaic					
Ocean Thermal					
Biomass Electric					
Other Non-Fossil		0.1			
Total Electric Generation		19.9	20.18	23.20	22.67

[a]Includes solar thermal.

Electric Generation, 2020
(Quadrillion Btu)

	PILOT	FOSSIL2	BNL/DJA	ETA-MACRO	LEAP
Total Coal		12.0	13.27[a]	11.82	11.30
Conventional Coal		5.8	5.84[a]	2.13	4.50
Coal Combined Cycle		5.5	3.14	9.69	3.80
Coal FBC		0.7	1.07		1.30
Coal Steam/DH			0.50		
Coal Combined Cycle/DH					
Coal FBC/DH					
Coal Steam/COG			1.65		
Coal FBC/COG			1.07		
Other Coal Electric					1.70
Total Oil		0.8	0.03		0.16
Oil Steam			0.03		
Oil Combined Cycle					
Oil-Coal Steam					
Gas Turbine					0.02
Total Energy System					
Oil Steam/DH					
Oil Combined Cycle/DH					
Oil Steam/COG					
Gas Turbine/COG					
Fuel Cell					0.04
Other Oil Electric					

[a]Includes electricity generated by burning wood in coal steam plants.

Electric Generation, 2020 (Cont.)
(Quadrillion Btu)

	PILOT	FOSSIL2	BNL/DJA	ETA-MACRO	LEAP
Total Gas		0.1			0.29
Gas Steam					0.15
Gas Turbine					0.14
Total Enegy System					
Gas Steam/DH					
Gas Steam/COG					
Gas Turbine/COG					
Fuel Cell					
Other Gas Electric					
Total Nuclear		7.7	6.31	14.24[a]	13.74
LWR		7.7	6.31	14.12	13.70
LMFBR				.12[a]	0.04
Other Nuclear Electric					
Hydroelectric and Geothermal		1.6	1.89	2.39	1.33
Solar Electric		0.2	0.98	0.0	
Other Non-Fossil Electric		0.6	1.1		0.77[b]
Wind Energy System		0.5	1.1		
Photovoltaic					
Ocean Thermal					
Biomass Electric					
Other Non-Fossil		0.1			
Total Electric Generation		23.0	23.59	28.45	27.53

[a]Includes all advanced non-fossil sources of electricity except solar.
[b]Includes solar thermal.

Role of Synthetic Technologies

The primary role of coal-based synthetics is consistent across all models, that of substitution for oil and gas imports. The magnitudes, level of detail, and first dates of introduction differ across models depending on the mathematical construct of the model system.

ETA-MACRO, PILOT, and LEAP show nearly identical trends for synthetic generation in the post-1995 period projected while FOSSIL2 and BNL/DJA show similar behavior to year 2005. The similarities in these trends are dominated by the farsightedness or simulation constructs of the model formulations.

The BNL/DJA synthetics production growth rate is substantially lower than FOSSIL2 in the years 2005 to 2015. The inventory of older stock, the associated capital costs incurred in previous periods, and the reduced growth rate in the cost of crude oil serve to moderate the pressure for substantial additions to coal synthetics production capacities for BNL/DJA. The long-term trends (post-2015 period) across the two models show parallel behavior.

Since ETA-MACRO has only one category for coal synthetics which it first introduces in 1990, it is difficult to know what the divisions are between synthetic gas and liquids. It appears reasonable to assume that at least some portion of it must be liquids since the other four models project the need for coal liquids starting between 1990 and 2005. The date of introduction of all coal synthetic technologies by PILOT is affected not only by its cost effective date but also by the import-export trade balance constraint. Methanol is the first coal-based synthetic to be introduced in both FOSSIL2 (1980) and BNL/DJA (1990). Methanol does not appear explicitly in the other models. The level of methanol production stabilizes by 1990 in FOSSIL2, whereas the methanol production projected by BNL/DJA continues to grow through 2025 making a substantial impact on the demand for motive power in the long term.

High Btu coal gas is projected for earliest introduction by the BNL/DJA system (1985) but, thereafter, BNL/DJA exhibits the slowest growth for this technology among the four models. The lower high Btu coal gas production growth rate for BNL/DJA results from the cost effectiveness of alternative coal synthetic technologies (e.g., coal liquids, coal methanol, medium Btu coal gas). Medium Btu coal gas is the preferred option for industrial and utility uses, methanol for motive power and coal liquids substitute for oil. Both methanol and coal liquids act to substitute for imported oil in the BNL/DJA system. Similarly the LEAP run concentrates most of its relatively extensive synfuel growth in the liquefaction and medium Btu gasification technologies rather than high Btu gasification.

Finally, the steadily increasing ratio of primary oil equivalents for motive power to total primary oil indicates that liquids are not only a short-term but also a long-term energy problem. For ETA-MACRO, the large energy gap satisfied by coal synthetics and an unidentified "backstop" technology also point to the persistent problem liquids are likely to constitute in the long term.

FIRST COMPETITIVE YEAR FOR SYNTHETIC FUEL PRODUCTION

	PILOT	FOSSIL2	BNL/DJA	ETA-MACRO	LEAP
Coal Liquids	2000	1990	2005	1990[a]	2000
Methanol		1980	1990		
High Btu Coal Gas	1995	2000	1985		2000
Medium Btu Coal Gas		1995	1990		2000
Solid Waste to Solid Fuel					
Solid Waste to Gaseous Fuel					

[a]ETA-MACRO incorporates one technology representing all coal synthetics.

CROSS MODEL COMPARISON

RATIO: PRIMARY OIL EQUIVALENTS FOR MOTIVE POWER TO TOTAL PRIMARY OIL[a]

Year	FOSSIL2	PILOT	ETA/MACRO	BNL/DJA[b]	LEAP
1980		*		0.59	0.45
1985		*		0.58	
1990		0.52		0.61	0.58
1995		*		0.70	
2000		0.64		0.73	0.79
2009		*		0.99	
2010				1.02	1.07
2015				1.12	
2020				1.17	
2025				1.31	1.38

Ratio for 1977: 0.55

*Insufficient Data Available

[a] The ratio measures the ratio of primary oil equivalents of liquids to transportation versus the total primary oil available from domestic crude production, oil imports and oil shale. Values greater than one are possible when coal liquid synthetics are produced to supplement other conventional oil production.

[b] Fractions greater than 1.0 indicate use of synthetic liquid substitutes.

SYNTHETIC FUEL PRODUCTION, 1990
(Quadrillion Btu)

	PILOT	FOSSIL2	BNL/DJA	ETA-MACRO	LEAP
Coal Liquids	0.0	0.1	0.0		0.0
Methanol		0.5	0.1		
High Btu Coal Gas	0.0	0.0	0.1		0.0
Medium Btu Coal Gas		0.0	0.4		0.0
Total Coal Synthetics	0.0	0.6	0.6	0.5[a]	0.0
Solid Waste to Solid Fuel					
Solid Waste to Gaseous Fuel					
AES	0.0				
Total Synthetic Production	0.0	0.6	0.6	0.5	0.0

[a]ETA-MACRO incorporates one technology representing all coal synthetics.

SYNTHETIC FUEL PRODUCTION, 2000
(Quadrillion Btu)

	PILOT	FOSSIL2	BNL/DJA	ETA-MACRO	LEAP
Coal Liquids	3.7	1.4	0.0		2.6
Methanol		0.5	1.3		
High Btu Coal Gas	1.6	0.3	0.1		0.4
Medium Btu Coal Gas		1.5	1.3		9.8
Total Coal Synthetics	5.3	3.7	2.7	8.3[a]	12.8
Solid Waste to Solid Fuel					
Solid Waste to Gaseous Fuel					
AES	2.6				
Total Synthetic Production	7.9	3.7	2.7	8.3	12.8

[a]ETA-MACRO incorporates one technology representing all coal synthetics.

SYNTHETIC FUEL PRODUCTION, 2010
(Quadrillion Btu)

	PILOT	FOSSIL2	BNL/DJA	ETA-MACRO	LEAP
Coal Liquids		4.6	2.6		7.2
Methanol		0.5	3.4		
High Btu Coal Gas		1.4	0.3		1.6
Medium Btu Coal Gas		4.8	2.7		14.2
Total Coal Synthetic		11.3	9.0	20.0[a]	23.0
Solid Waste to Solid Fuel					
Solid Waste to Gaseous Fuel					
AES					
Total Synthetic Production		11.3	9.0	20.0	23.0

[a]ETA-MACRO incorporates one technology representing all coal synthetics.

SYNTHETIC FUEL PRODUCTION, 2020
(Quadrillion Btu)

	PILOT	FOSSIL2	BNL/DJA	ETA-MACRO	LEAP
Coal Liquids		8.0	3.6		11.0
Methanol		0.5	3.4		
High Btu Coal Gas		6.6	1.0		2.7
Medium Btu Coal Gas		4.5	3.2		17.1
Total Coal Synthetic		19.6	11.9	30.0[a]	30.8
Solid Waste to Solid Fuel					
Solid Waste to Gaseous Fuel					
AES					
Total Synthetic Production		19.6	11.9	30.0	30.8

[a]ETA-MACRO incorporates one technology representing all coal synthetics.

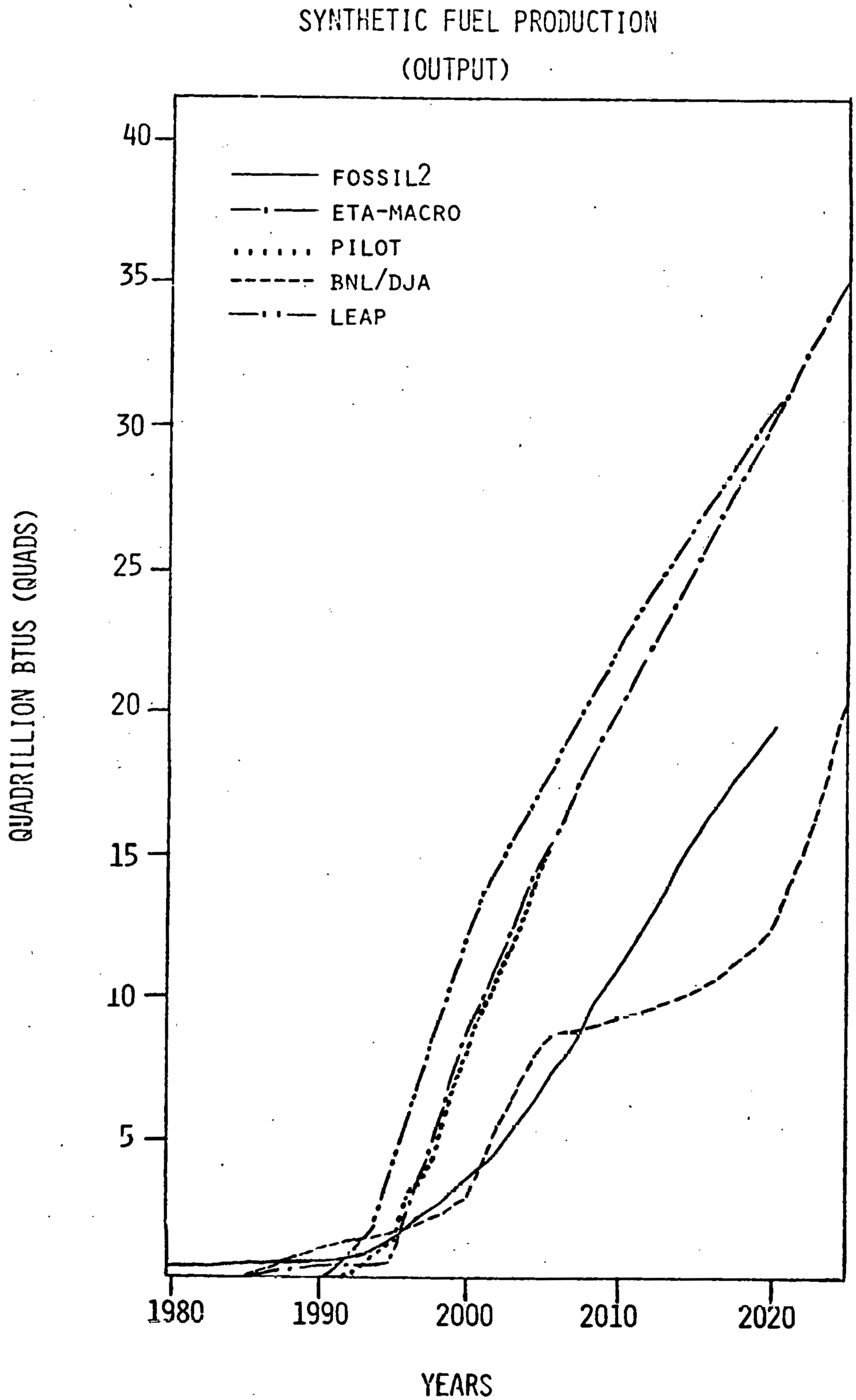

SYNTHETIC FUEL PRODUCTION
(OUTPUT)
FOSSIL2
ETA-MACRO
PILOT
BNL/DJA
LEAP
QUADRILLION BTUS (QUADS)
40
35
30
25
20
15
10
5
1980
1990
2000
2010
2020
YEARS

Figure 29

MAJOR CONCLUSIONS

In projecting the long-term state and evolution of the nation's energy and economic systems, the EIA has recognized the potential utility of several energy-economy models, each with unique, structural representations and views of the same underlying systems. Given the acknowledged uncertainties inherent in long-term projections, this comparative assessment is motivated by EIA's interest in addressing two specific issues. The first is the degree to which the combination of the assumptions and the structure and content of each methodology influences the projections obtained. The second is the examination of attainable patterns of future energy supply, conversion, and end-use which, in turn, depends on the interactions of the assumptions and the alternative structural views of the energy and economic systems.

Several major conclusions dominate the comparison of the alternative projections of the evolving U.S. energy and economic systems. In each projection, certain trends are in evidence which form a consensus among the results from the various models.

There is continued positive growth in total, primary energy consumption in spite of the continuous escalation of the real prices of primary resources. Though the levels and patterns of growth differ among the projections, there is no evidence of an asymptotic upper limit for primary energy consumption through the first quarter of the next century.

From the projections, there is also the implication that liquids constitute both a short- and long-term energy problem for the United States. In the FOSSIL2 and PILOT estimates, oil imports continue to provide a significant fraction of the total liquids demand to the end of their respective time horizons. In the ETA-MACRO projection, imports disappear by 2020 with the increased penetraton of a "backstop" technology, which is priced competitively with imports of oil and gas. As the non-electric backstop is not specifically identified and as it is projected to be a significant component of total primary energy, its presence amplifies the liquids and, perhaps, even the import problem. Only in the BNL/DJA projection are oil imports replaced by energy from identifiable domestic resources and technologies. However, the sporadic reappearance of imports suggests that the liquids balance between the growth in domestic demand and the growth potential of domestic supply is tenuous. Thus, in the context of the future growth, structure, and stability of world oil markets, none of these projections can be viewed as especially comforting.

Another prominent feature of these projections is the predicted role of electricity in the energy system. The models estimate the growth of electricity generation to be in the range of 2.5 to 3.1 percent per annum over the long-run. Although this projected growth is moderate by historical standards, an increasing fraction of total primary energy consumption is devoted to providing electricity. It is projected that, through 2020, the long-term shift toward the increased centralization of the energy system will slow but will not reverse.

The share of electricity generation provided by nuclear power increases continuously over the time horizons considered for each model. In the pre-2000 period, the growth of nuclear power exceeds the growth of total electricity generation with the result that, by 2000, nuclear energy inputs are estimated to account for one-quarter to one-third of total electric inputs. This differential growth continues after 2000 in the FOSSIL2, ETA-MACRO, and LEAP projections. However, in the BNL/DJA post-2000 estimates, nuclear power grows only slightly faster than electric generation as its allowable penetration was constrained to reflect the pattern of growth in the period 1990 to 2000 in the EIA case specification. Finally, the projections indicate an increased reliance on domestic coal resources for direct combustion, synfuels production, and electric generation. Although the details of coal consumption and conversion vary among the estimates, there are marked similarities in the trends and even the levels of coal consumption provided by the models.

The trends, enumerated above, are sufficiently "robust" among the projections to appear not influenced by the particular structural representations of the energy and economic systems in each of the models. However, there exist certain fundamental differences in the details of these projections that are attributable to differing model structures and that are of major consequence to public policy.

The patterns of the timing and growth of the synfuel industries differ greatly among the projections. To the year 2005, the estimated trends of market penetraton are paired--ETA-MACRO, PILOT, and LEAP versus FOSSIL2 and BNL/DJA. After 2005, ETA-MACRO and LEAP follow a similar path while FOSSIL2 and BNL/DJA form distinct trends. ETA-MACRO and FOSSIL2 project a continuation of the trends established for previous time periods. In the BNL/DJA projection, there are inflection points in the trend line due both to the temporal and static energy-economy interactions as they affect energy demand and supply and to the market penetration algorithm in TESOM. Most importantly, the differences in the estimates of synfuels production activity are related directly to the characteristics, both explicit and implicit, of market penetration provided by each methodology.

There is substantial variation in the abilities to incorporate and, hence, estimate the details of energy end-use in the alternative methodologies. Indeed, of the five models chosen for this exercise, only two provide such detail and comparisons of these projections and methodologies are frustrated by differences in accounting conventions and technology characterizations (efficiencies, costs, etc.). In addition, the informational complexities of energy end-use all but preclude the modeling of meaningful market penetration representations so common to energy supply and conversion technologies. The fact that the penetration levels of many new or advanced end-use technologies are often fixed by assumption is sufficient to identify energy end-use modeling as a topic of concern to the analysis and projection of the energy and economic systems.

The models differ in the extent to which knowledge of the future is assumed and employed within each structure and in the interactions (energy-energy and energy-economy) which emerge from the static and dynamic functional relationships contained in each system. Unfortunately, the differences which appear in the projections (e.g., the growth of electric and non-electric energy demands, the energy-GNP ratios, etc.) cannot be linked causally to one of these structural differences in isolation. Rather, it is the structural differences, taken as a set, which provide the explanation for the disparities. It is important to note, however, that much of the predictive power of any methodology is provided by the credibility of its set of assumptions.

The similarities and differences contained in this set of projections give rise to many unresolved issues which should be addressed to improve the usefulness and timeliness of the information from such analyses. Among these are:

- The political "realities" of nuclear power and its fuel cycle;

- The transportation, infrastructural, political, and environmental problems associated with the magnitudes of projected coal production and consumption;

- Knowledge of the technical, behavioral, and economic characteristics of energy end-use;

- The importance of international energy-economy interactions to the projection methodology (e.g., export determination in PILOT, the balance of payments adjustment in BNL/DJA, etc.); and

- The implications for model behavior and analytical interpretation imposed by the selection of specific functional forms (e.g market penetration, substitutability versus complementarity, dynamics, etc.).

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APPENDIX - GUIDELINES

The following is a list of guidelines which were forwarded to the participants and followed to the extent possible:

Long Term Analysis Forum - Driving Variables Definition

- Base year and base dollars are all set in 1978.*

Economic Sector Assumptions - select only those which are applicable.

1. Exogenous Components of Final Demand

   Government expenditures proportional to GNP. Exports proportional to GNP in models requiring exogenous assumptions.

   As a guideline for models which may require it, the government expenditure/GNP ratio may be taken as 0.194 in 1985, 0.200 in 1990, and 0.210 in 2000.

2. Population and Labor Force

   A. Census series II projection, July 1977. Total Population (in thousands) listed below by 5-year period:

1975	213.540
1980	222.159
1985	232.880
1990	243.513
1995	252.750
2000	260.378
2005	267.603
2010	275.335
2015	283.164
2020	290.115
2025	295.742

   B. Labor force taken from the monthly labor force review, July 1978 for data up to 1990. Extrapolation thereafter based on labor force assumed at 46% of the population. Projections (in thousands) listed below by 5-year period.

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* To convert 1975 dollars to 1978 dollars, multiply by 1.190 per specification of J. Pearson.

1975	94.800
1981	101.800
1985	107.700
1990	112.600
1995	117.100
2000	120.700
2005	124.400
2010	128.200
2015	132.000
2020	135.300
2025	137.900

3. Technological Changes

A. All non-energy sectors

Labor augmenting technical progress set at 2% per year.

B. Energy sectors

For models without process detail, input aggregate technological change implied by MRG assumptions and consistent with the non-energy sector changes.

4. Government Policy

Btu taxes
NONE AT PRESENT
Btu subsidies

5. Unemployment rate

1976	7.4
1977	6.7
1978	6.4
1979	6.6
1980	6.9
1981	6.5
1982	6.4
1983	6.3
1984	5.8
1985	5.6
1986	5.6
1987	5.2
1988	5.0
1989	4.8
1990	4.3
Beyond 1990	4.3

6. Growth Rate of Real Gross National Product %/Year, for those models which need it.*

1975-1980	4.5
1980-1995	3.2
1995 and Beyond	2.4

7. Time Frame

The time frame of simulation will vary by model. The longer the period the model can run for, the better. An arbitrary cutoff of 2025 can be used.

Environmental

1. Electric Utility Emissions Standards

Best available control technology

(a) 90% of sulfur removal
(b) 0.033 lb. particulates/million Btu
(c) State Implementation Plans

Supply

Parameters to which the distribution of coal production between eastern and western sources is particularly sensitive were chosen as supply side driving variables.

1. Mine Factor Input Costs

Constant at current labor contract prices.

2. Surface Mine Taxes and Costs

No change over 1978.

3. Freight Rates (are imbedded in each model)

Assume these increase 15% overall during the 1978 and 1985 period and remaing constant thereafter.

Demands: Only if Required

1. Demands: The aggregate energy demands specified here are required only for the energy sector models. The electricity, industrial steam-coal, and synfuels

*This was taken from a DRI-MARCO "trend-long" forecast to 1995 and adjusted for imported oil prices (R. Crockett).

growth rates given here are NOT to be used to constrain the results of those models. The industrial steam-coal requirements exclude demands for metallurgical coal, which are left up to the discretion of the individual modelers. In 1975, industrial steam-coal demand was 64 million tons, while metallurgical coal demand was 83 million tons for a total industrial demand of 146 million tons.

For models which require demand by region, the modelers are requested to select a reasonable reference forecast and to scale the demands so as to match the national total specified here (1975 base).

(a) Aggregate energy: 2.3% annual growth rate (up to 125 quads by 2000)

(b) Electricity: 3.9 average annual growth thru 1995.

(c) Industrial steam coal: 6% average annual growth with 8% maximum permitted annual growth.

(d) Synfuels: 5 quads of coal required by year 1995 (target)

(e) Exports: 50 million tons of metallurgical coal exports per year increasing linearly to 70 million tons per year in 2000 and 10 million tons of steam coal exports in 1975 increasing linearly to 30 million tons per year in 2000. Exports increase linearly after year 2000 to 85 million tons per year for metallurgical coat and 40 million tons per year for steam coal in 2025.

2. Power Plant Capital Costs, O&M Costs (in 1978 $) and Heat Rates

A capital cost, O&M cost and heat rate are specified only for a "reference" power plant. The modelers are requested to maintain the proportions between the characteristics of this reference power plant and those of other types of power plants in other regions already embedded in their models. Characteristics of a combined power plant are specified in view of its status as a relatively new technology.

(a) Bituminous coal-fired plant in the east central region - including scrubbers.

Capital Cost = $666/kW
O&M Cost = 4.03 mills/kWhr
Heat Rate = 9980 Btu/kWhr in 1995
Economic Life = 35 years

(b) Combined cycle power plant in the east central region (include coal gasification facilities - medium Btu coal gasifier).

Capital Cost = $738/kW
O&M = 4.17 mills/kWhr
Heat Rate = 8530 Btu/kWhr in 1995 (assume variation with time)
Economic Life = 35 years

(c) See tables for other new technology characterizations.

(d) Others: maintain proportions with characteristics of (a) already in models. Internal definitional consistency for technological characterizations is left to the discretion of the modeler for other years and conventional technologies.

3. Prices of Alternative Fuels

Fuel Switching: Left to economic calculations included in the models: Do not include mandatory fuel switching or restrictions on switching. Do not impose any exogenous annual limits to resource usage.

(a) Crude Oil:

(i) Imports: $15/bbl landed price in 1978 - 1985. 4.3% real annual price growth/year to $18,50/bbl until 1990; 4.7% thereafter until reach $30/bbl, 2.5% annual growth thereafter.

(ii) Domestic Price: Linear increase from the current price to the world price in 1980. Domestic price equals world price thereafter.

(b) Natural Gas: Price of natural gas at Btu equivalent price of domestic crude oil, and imports. Short-term use: natrual gas act NGPA.

(c) Cumulative Domestic Resources Available. Use USGS 725 mean values. As a guideline

Oil:	900 Quads (includes shale oil and EOR)
Natural Gas:	723 trillion cubic feet
Shale Oil:	up to 1 Quad/year at $22.50/bbl up to 3 additional Quads/year at $30/bbl beginning in 1995. 43 Quads is total availability.
	These include secondary and tertiary processes

(d) Modelers are requested to use their best judgment in determining prices for the remining resource.

4. Maximum Nuclear Power Plant Capacity (with an assumed capacity factor of 65%).

   (a) 100 GW in 1985
   (b) 150 GW in 1990
   (c) 225 GW in 2000
   (d) open

5. Cost of Capital

   For established technologies, 8% real rate of return of investment after taxes. An additional risk premium may be assigned for new technologies at the direction of the modeler. For models which need further definition, assume a capital recovery factor of 15% for plants with a 30 year life. This includes amortization, property taxes (interest during construction), insurance, legal fees, etc.

6. Contribution of Hydroelectric Generation

   (a) 0.30 trillion kWhr in 1975, rising linearly in 1995.

   (b) 0.32 trillion kWhr in 1995 and thereafter.

   It was decided to be explicit about hydroelectric generation assumptions to prevent these from driving the intermodel differences.

Table 1 ARC Support Study Input Assumptions
Cumulative (1980-2025) Primary Resource Limits
Use USCS725 as the Mean Values

	(10^{15} Btu)
Domestic including secondary and tertiary processes	900.0
Shale Oil	43.0
Domestic Natural Gas	745.0

Imported Gas
Yearly Consumption Limits (Quads)

1985		1990		1995-2025	
upper	lower	upper	lower	upper	lower
2.50	0.5	3.2	0.5	3.50	0.5

		Total Availability
Enhanced Gas Recovery:	\$ 5.17/MMBtu	$200x10^{12}$ CF
Enhanced Oil Recovery:	\$ 30/bbl	$40x10^{9}$ bbl

Table 2 ARC Support Study Input Assumptions
Suggested New Technology Production Limits (10^{15} Btu)[a]

Technology	YEAR 1980	1985	1990	1995	2000	2005	2010	2015	2020	2025
Low & Med-Btu Coal Gas;[c] Comb. Cycle Base Load Electric, Advanced Gasifier	0.0	0.0	0.39	0.78	3.91	7.45	13.97	14.90	14.90	14.90
Ocean Thermal	0.0	0.003	0.02	0.13	0.52	1.04	1.87	2.06	2.06	2.06
Biomass Electric	0.0	0.04	0.10	0.18	0.72	1.45	2.6	2.85	2.85	2.85
Solar Thermal	0.0	0.003	0.02	0.18	0.72	1.45	1.6	2.85	2.85	2.85
Hydropower[b]	0.0	0.40	0.80	1.30	1.3	1.3	1.3	1.3	1.3	1.3
Photovoltaics	0.0	0.003	0.02	0.16	0.70	1.40	2.6	2.85	2.85	2.85
Wind Energy System	0.0	0.003	0.02	0.23	0.85	1.65	3.0	3.2	3.2	3.2
Atmos. Fluidized Bed	0.0	0.0	0.0	0.2	0.80	1.60	3.0	3.2	3.2	3.2
Geothermal Electric	0.0	0.22	0.55	1.34	3.50	4.00	5.00	6.00	6.00	6.00

[a] These are maximum levels. Justification for exceeding these levels will be required by the modelers. These units are in terms of inputs of useful energy in Quads.

[b] Hydropower: This represents the new "low head" hydropower. Total Hydroelectric should be limited to those levels set on page 5.

[c] Primary coal input equivalents.

Table 3 ARC Support Case Study Input Assumptions
Characterization of New Electric Generation Technologies[3]

Technology[2]	Capital Cost (1978$/kWe)			O&M (mills/kWh)	Conv. Eff.	Capacity Factor (%)	Plant Capacity
	1985	1990	1995 and on				
Low & Med-Btu Coal Gas; Comb/ Cycle Base Load Electric, Advanced Gasifier	738	738	738	4.17	0.40	65	100 mWe
Ocean Thermal*	6000	2300	1800	3.0	-	80	-
Biomass Electric	1000	900	800	7.0	0.30	65	-
Solar Thermal*	1800	1400	1300	3.0	-	50	-
Hydropower	900	900	900	2.5	0.34	50	-
Photovoltaic*	3700	1920	1100	3.0	-	26	-
Wind Energy System*	1300	1000	750	10.0	-	40	-
Atmos. Fluidized Bed	-	-	583	5.7	0.34	65	-
Geothermal Electric	800	800	800	32.0	-	85	-

*For renewable primary resource accounting, assume coal equivalent efficiencies.

[1]Left to discretion of modeler.

[2]Lead time required for all of these is 5 years.

[3]Project life for all these plants is assumed to be 35 years.

Table 4 ARC Support Case Study Input Assumptions
Characterization of New Synthetic Fuel Technologies

Technology	Capital Cost ($/$10^6$ Btu output)			O&M ($/$10^6$ Btu output)	Conv. Eff.	Capacity Factor (%)	Plant Capacity	Lead Time (years)
	1985	1990	1995 and on					
Coal Liquids	2.14	2.14	2.14	1.80	0.70	90	60 Mb/d	8
Methanol	0.85	0.85	0.85	1.75	0.60	90	87 Mb/d	8
Hi-Btu Coal Gas;								
Commercial, Eastern	1.95	1.95	1.95	1.30	0.47	90	250 10^9 Btu/sd	13 max.
Commercial, Western	1.77	1.77	1.77	1.12	0.67	90	250 10^9 Btu/sd	8
Advanced, Eastern	1.60	1.60	1.60	1.47	0.72	90	250 10^9 Btu/sd	8
Advanced, Western	1.45	1.45	1.45	1.12	0.75	90	250 10^9 Btu/sd	8
Med-Btu Coal Gas;								
Commercial, Eastern	1.73	1.73	1.73	0.73	0.57	90	50 10^{12} Btu/yr	8
Commercial, Western	1.73	1.73	1.73	0.73	0.75	90	50 10^{12} Btu/yr	8
Advanced, Eastern	0.80	0.80	0.80	0.43	0.80	90	60 10^{12} Btu/yr	-
Advanced, Western	0.80	0.80	0.80	0.43	0.80	90	60 10^{12} Btu/yr	-
Solid Waste to Solid Fuel	1.85	1.85	1.85	0.24	0.875	85	1700/Tons/day	-
Solid Waste to Gaseous Fuel	3.13	3.13	3.13	0.13	0.64	85	2000/Tons/day	-

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