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TECHNICAL-ECONOMIC MODELING IN ENERGY PLANNING

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ABSTRACT

A combined technological-economic model has been developed and applied to the assessment of alternative energy technologies and policies. The individual models that have been assembled are the Hudson-Jorgenson model of the economy and interindustry transactions, and the Brookhaven Energy System Optimization Model. Other data bases and fixed coefficient input/output models are employed as data sources and accounting frameworks to support this combined technological-economic model.

The combined model has been used to develop long-range projections of energy-economic relationships and to perform cost/benefit analyses of the U.S. energy R&D programs. The models assist in the comprehensive analysis of the interrelationships between technological change, the overall economy, and the environment as new resources and options such as conservation are implemented.

INTRODUCTION

The coupled technological-economic model developed by Brookhaven National Laboratory and Data Resources, Inc., represents a combination of the strengths of process analysis with econometrics. The two models that have been combined in this system are the Hudson-Jorgenson model of the U.S. economy and the Brookhaven Energy System Optimization Model (BESOM). Both of these models have been used individually for energy policy analysis and

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DISCLAIMER

technology assessment. In view of the highly technical nature of the energy infrastructure and of new technologies that may be developed for both centralized and decentralized applications, it is necessary to include technical detail and options in energy policy analyses. At the same time, economic and regulatory policies affect energy supply and demand and the need for certain technologies.

The Hudson-Jorgenson Model was applied in 1974 to the analysis of the effect of taxes on energy demand and, in turn, on economic growth. That work was performed for the Ford Foundation Energy Policy Project [1] and indicated a rather flexible relationship between energy and GNP over the long run. The Energy System Model and the Reference Energy System that supports it have been applied to the assessment of energy technologies and R&D priorities for the Office of Science and Technology in 1972, [2] for the Atomic Energy Commission in 1974, [3] and for the U.S. Energy Research and Development Administration (ERDA) in 1975. [4]

When employed individually, each model was appropriate for the analytical purpose but somewhat deficient in scope. The energy sector model, BESOM, includes a process description of new technologies that are available or under development. Since many of these are of a different character and nature than technologies now in use, a process approach is more appropriate than an econometric representation of technological change. The energy sector model, on the other hand, contains no behavioral detail in terms of the response of the consumer to changes in energy prices and income or of the role of energy in economic growth and development. The combined technological economic model overcomes these deficiencies and this combination enhances the utility and scope of each individual model.

The technological-economic model has been applied to the evaluation of alternative energy policies to achieve specific oil import objectives for the U.S. by the year 2000. [5,6] The policies evaluated included a Btu tax policy to achieve the objectives and an alternative policy involving energy R&D on new sources and more efficient utilization systems coupled with a lower Btu tax. The results indicated that the R&D policy with the lower tax level was preferred and had economic benefits when compared with the tax-only policy that far exceeded the costs of the required R&D program. Work has been completed on long-term energy-economic projections as a basis for energy policy. The current status of the combined model and plans for future development are described in a recent paper. [7]

HIERARCHY OF POLICY CONSIDERATIONS

The policy considerations that may be dealt with using the model are illustrated on Figure 1. This figure identifies the important components of policy and the issues that arise with respect to each; it does not identify the models employed. Indeed, some components are not dealt with directly by the models but require separate investigation and analysis outside of the models, e.g., the environmental and society-lifestyle components. Models and data bases are employed to analyze the economic sector; the technical system (in this case the energy system); the individual technologies that comprise the system; and the capital, labor, energy, and material resources on which the system is based. Several individual models and data bases are required to cover the full scope. They may be used individually on policy questions that pertain to only one or two components of the system hierarchy or in such combination as may be required for more complex issues. Figure 2 indicates how the basic models and supporting systems fit together. The system is designed so that the models may be used individually or in various combinations. Provision is made for close monitoring of critical information flowing between models.

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

The energy system and technologies are modeled using a process or technological approach in which the efficiencies, cost, and environmental emissions of specific resources and technologies are described. The important information that this model provides is the price and availability of energy under specific technical policies and the environmental effects produced by the energy system.

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

DESCRIPTION OF SUPPORTING SYSTEMS

The energy sector optimization model and the economic model are supported by several data bases and analytical techniques. These include the following:

--Reference Energy System (RES): (Figure 3). A network diagram of the flow of energy from resources to end uses. End use devices are included to permit the analysis of conservation and fuel-switching options. The RES also allows for analysis on the basis of the second law of thermodynamics.

The RES is used as a standard format to represent the fuel mix and technologies employed in an analysis performed with any model of adequate sectoral detail.

--Energy Model Data Base (EMDB): (See Figure 4 for process elements included in EMDB.) A data base containing efficiency, environmental, and cost information on technologies included in the energy sector model.

DESCRIPTION OF BESOM

The structure and content of the Brookhaven Energy System Optimization Model (BESOM) is described in matrix format in Figure 5 and in graphical form in Figure 6. Other information pertinent to the model is given on the following figures.

Figure 7--List of equations included in BESOM

Figure 8--List of objective functions available as options in BESOM

Figure 9--Output information provided by BESOM

BESOM is quantified and solved for a single time-period. Constraints on the level of employment of new technologies must be developed based on consideration of the timing of the research, development, and commercialization program. Existing capital stock available in the future year for which the analysis is performed must also be estimated.

A Time Phased or Dynamic Energy System Optimization Model (DESOM) has been developed by Marcuse and Bodin [8] with an explicit representation of capital investment and the dynamics of introduction and replacement of facilities. This model also includes a representation of the complete nuclear fuel cycle which is not included in BESOM. The DESOM model was applied in a study performed by the National Academy of Sciences Committee on Nuclear and Alternative Energy Systems (CONAES). Work is in progress on the coupling of DESOM to the Hudson-Jorgenson model to provide a representation of the timing of future capital investment in energy supply and utilization facilities.

The time phased model, DESOM, determines the optimal allocation of resources over time, given a complete description of future demands and total resource availability. The model effectively has perfect foresight and acts to immediately avoid any problems that are defined in future time periods. Thus it is impossible to "shock" the model and test the reaction to some unforeseen circumstances without decomposing the model. As an alternative, to provide the capability to introduce "shocks" and test the reaction or resilience of the system, a time-step version of the model also has been developed.

A multi-regional version of BESOM is also under development for regional analysis within the U.S. as well as for purposes of international energy analysis. Regional information is particularly important in the evaluation of environmental information produced by the models.

While the current version of BESOM contains some detail on specific end use devices, it is clear that additional detail is needed for the complete analysis of the energy and economic consequences of alternative conservation policies. Work has been completed by Marcuse and Carhart [9] on a residential sector submodel that fills this need in that one sector. Work is in progress on similar models for other energy use sectors including the energy intensive industrial sectors.

The Reference Energy System and BESOM may also be applied to the analysis of decentralized technologies. The following decentralized technologies have recently been incorporated in the model.

--cogeneration,

--fluidized bed combustion, and

--low Btu gasifiers.

Solar heating and cooling systems, fuel cells, and total energy systems were incorporated in the earlier versions of BESOM.

THE COMBINED TECHNOLOGICAL-ECONOMIC MODEL

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

The Hudson-Jorgenson model of the economy is based on a system of accounts for the private domestic sector of the U.S. economy including final demand, primary inputs, and interindustry transactions. The system of accounts is represented in Figure 10. The energy commission sectors and energy product sectors are modeled explicitly in BESOM but are implicit in the economic model. The resource-to-industry sector coefficients in the economic model are determined by BESOM.

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

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

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

A simplified diagram of the linkage between BESOM and the Hudson-Jorgenson model is shown in Figure 11. The two models are solved independently but with the indicated information transferred between the two. The solutions are repeated until convergence is obtained. At each step the fuel mix and prices from the energy sector model are inserted into the Hudson-Jorgenson model while the demand for energy services determined by the economic model are inserted into BESOM.

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

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

Energy Resource Sectors

1. Underground coal
2. Strip-mined coal
3. Domestic oil
4. Shale oil
5. Imported oil
6. Domestic natural gas
7. Imported natural gas
8. Hydro energy
9. Nuclear energy
10. Geothermal energy
11. Solar energy

Secondary Energy Forms and Energy Product Sectors

1. Base load miscellaneous electric
2. Intermediate load miscellaneous electric
3. Peak load miscellaneous electric
4. Storage and synthetic fuel
5. Miscellaneous thermal, low temperature
6. Miscellaneous thermal, intermediate temperature
7. Miscellaneous thermal, high temperature
8. Ore reduction (iron)
9. Petrochemicals
10. Space heat
11. Air conditioning
12. Water heat
13. Air transport
14. Truck, bus
15. Rail
16. Automobile

Industry Sectors

1. Agriculture, nonfuel mining, and construction
2. Manufacturing, excluding petroleum refining
3. Transportation
4. Communications, trade, and services

5. Coal mining
6. Crude petroleum and natural gas
7. Petroleum refining
8. Electric utilities
9. Gas utilities

<u>Primary Inputs</u>

1. Imports
2. Capital services
3. Labor services

<u>Final Demands</u>

1. Personal consumption expenditures
2. Gross private domestic investment
3. Government purchases of goods and services
4. Exports

Some specific attributes of the models are listed in Figures 12 and 13. Applications of the model system are listed in Figure 14.

CONCLUSIONS

This conclusion section will deal with some of the management and institutional aspects of energy modeling. While the need for energy modeling and an analytical basis for energy policy as described in this paper is evident, the ultimate role of models and analysis will depend largely on the directions that this work takes in the next few years and on the institutional relationships that evolve. Two important considerations involve the role of very large computer models and the degree of centralization of energy models. These are somewhat related, as centralized and well funded modeling activities are more likely to develop very large models, but will be discussed as separate issues.

Regardless of the institutional structure, there is a natural tendency to develop models that are larger in size and broader in scope. Indeed, the state-of-the-art of mathematical analysis and computer science may be such that the ability to formulate and computerize very large models exceeds the capability to interpret the output and policy implications of such models. Very large models that can be generated by the combination of individual models can be quite valuable in analyzing complex interrelationships but must be used with care. Such couplings, when computerized, make interpretations a much more difficult process. A manual approach, where information obtained from one model is interpreted by an analyst and provided as input to another model is more tedious but does assist considerably in the interpretive process. The decision to interface models on the computer as opposed to a manual approach is quite difficult and involves this basic trade-off between time and manpower requirements with the manual approach on the one hand, and interpretive problems with computerized approach on the other hand.

In most policy organizations a central modeling and analysis activity is required with a close relationship to policymakers. In the governmental context, such an activity should clearly not be an entirely closed, in-house effort. Modeling and analysis provide a unique opportunity to gather a diverse set of external opinions and viewpoints and to consider them in a disciplined and quantitative fashion. Thus, it is important that there be some related decentralized modeling activity that can involve a diverse set of analysts from industry, academia, and government. In this way modeling and analysis can enhance the intellectual basis for energy policy.

The availability of a decentralized and diverse set of models that enable many research groups to perform analyses related to policy issues is an attractive concept but also involves considerable practical problems. Some coordination is needed to provide basic data and assumptions, to prepare guidelines for model structure, and to validate and verify models, otherwise models could be used or misused to defend parochial positions by the improper manipulation of input parameters and assumptions. A coordination activity would serve to qualify the data, assumptions, and structure of models so that analysts and policymakers could interpret the results with some confidence that any differences between results were related to real policy issues rather than to differences in input data and assumptions. Individual modelers could, of course, use different data sets than those arising out of any coordination activity where there were honest differences of opinion; however, this must be noted rather clearly when the results are presented. The intent should not be to impose a uniformity of thought and viewpoint in any way but to ensure that different and perhaps controversial assumptions are clearly identified.

Improved coordination of decentralized models could be achieved by a variety of mechanisms including the development of data and format standards by professional societies and/or the establishment of centralized coordinating activities at the Federal level. Given that most government agencies have fairly large analytical groups, it would seem that such a coordinating function is quite compatible with other duties of these groups.

The methodologies described here focus on the introduction of technical and economic factors into a comprehensive framework for policy analysis and technology assessment. This coupling of technical and nontechnical factors is critical to energy where there is a complex mix of technical options for supply and conservation and of policy alternatives that may either supplant, or be supported by, specific technologies. In the final analysis, our long-term energy policy is based on technical realities--our ability to find and exploit new energy sources such as solar energy, fusion, and the breeder reactor. The evaluation of these alternatives also requires consideration of their economic and environmental consequences within a comprehensive energy-economic-environmental framework of the type described.

While the methodology described concentrates on energy, the approach may be generalized to other areas of technology that are closely realted to economic policy and social development. Work has begun on a Reference Materials System (RMS) [10] that describes the technical conversion required to exploit material resources and adopt them to specific uses. The Reference Material System is similar in concept to the Reference Energy System and provides an analytical framework for the substitution of alternative resources, renewable and nonrenewable, and the determination of resource, economic, and environmental consequences. When fully developed, this description of the materials system may be incorporated in the broader economic models. A similar approach may be taken to other technical areas, such as transportation, housing, and communications that are closely related to economic and social development. In order to facilitate coupling to the model of the overall economy, the technological system model should include the following features.

1. Description of alternative technical options that are now available or are projected as a result of R&D.

2. Definitions of capital, labor, energy, and material requirements to support specific technical options.

3. Definition of environmental effects produced by technology (during both construction and operation).

4. Specification of criteria as basis for selection among competing technical options (cost optimization, multi-objective optimization, market penetration, etc.).

Given the characteristics of the preferred technologies (resources, labor needs, and environmental effects) along with the price of the delivered services, the economic model determines the demand for the service and the overall economic impact on GNP, jobs, and inflation of the policy or technological option.

Finally, further research is required on methodologies for energy policy analysis. Econometrics is a proven methodology for economic analysis. Its strengths are the ability to capture a complex set of behavioral relationships in a well understood mathematical structure. The process analysis technique is also well developed and has the capability of representing engineering relationships. When formulated in a linear programming format with a cost-based objective function, the technique is rich in economic interpretation.

Other techniques that, with further development, may be useful in energy-economic analysis include game theory, bargaining models, and system dynamics. Game theory and bargaining models can provide for introduction of political considerations. System dynamics provide a rich structure in which dynamic relationships, causality, and feedback effects can be represented.

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POLICY CONSIDERATIONS

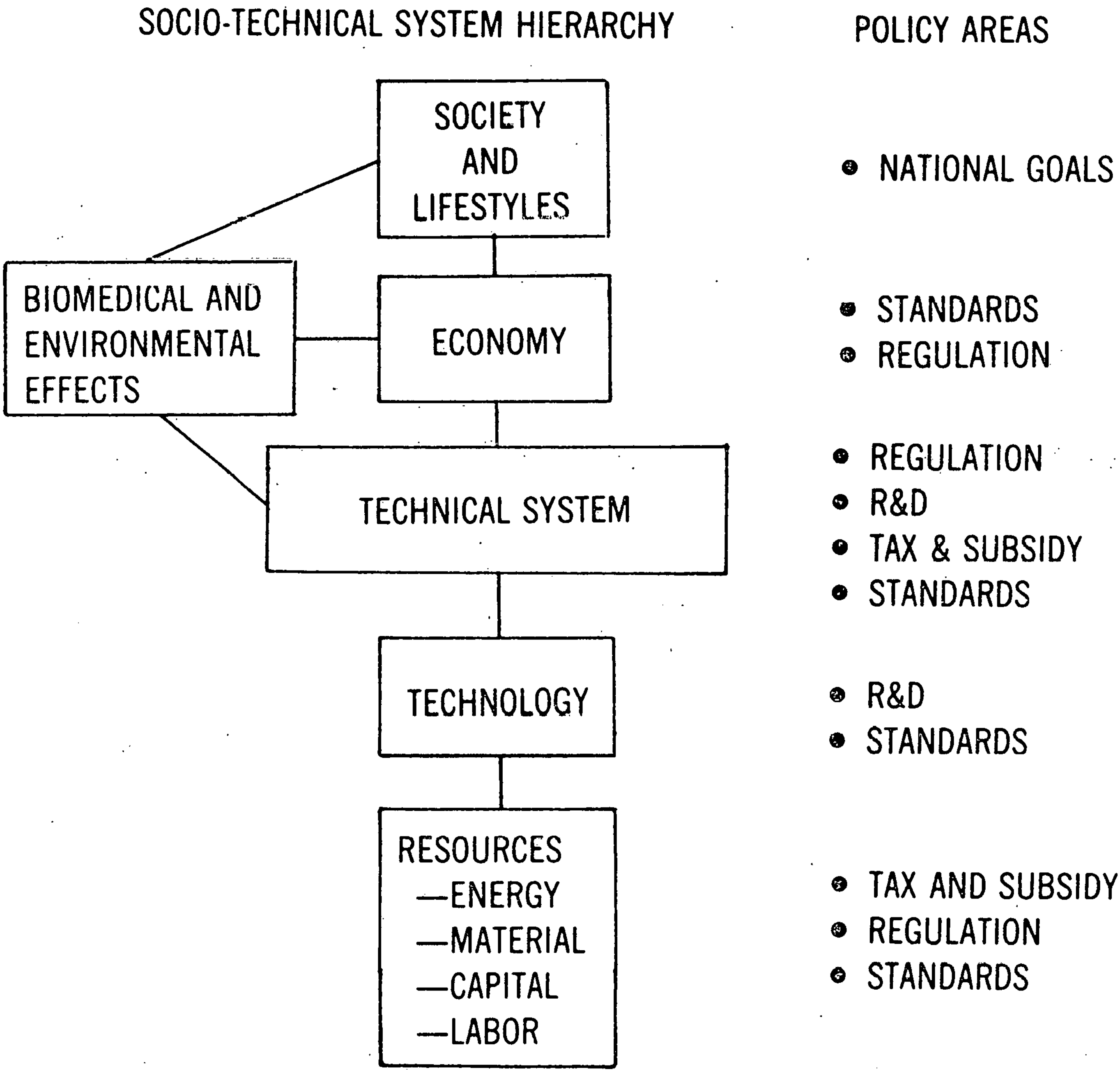

Figure 1 - Policy Considerations

ERDA ENERGY SYSTEM-ECONOMIC MODELS

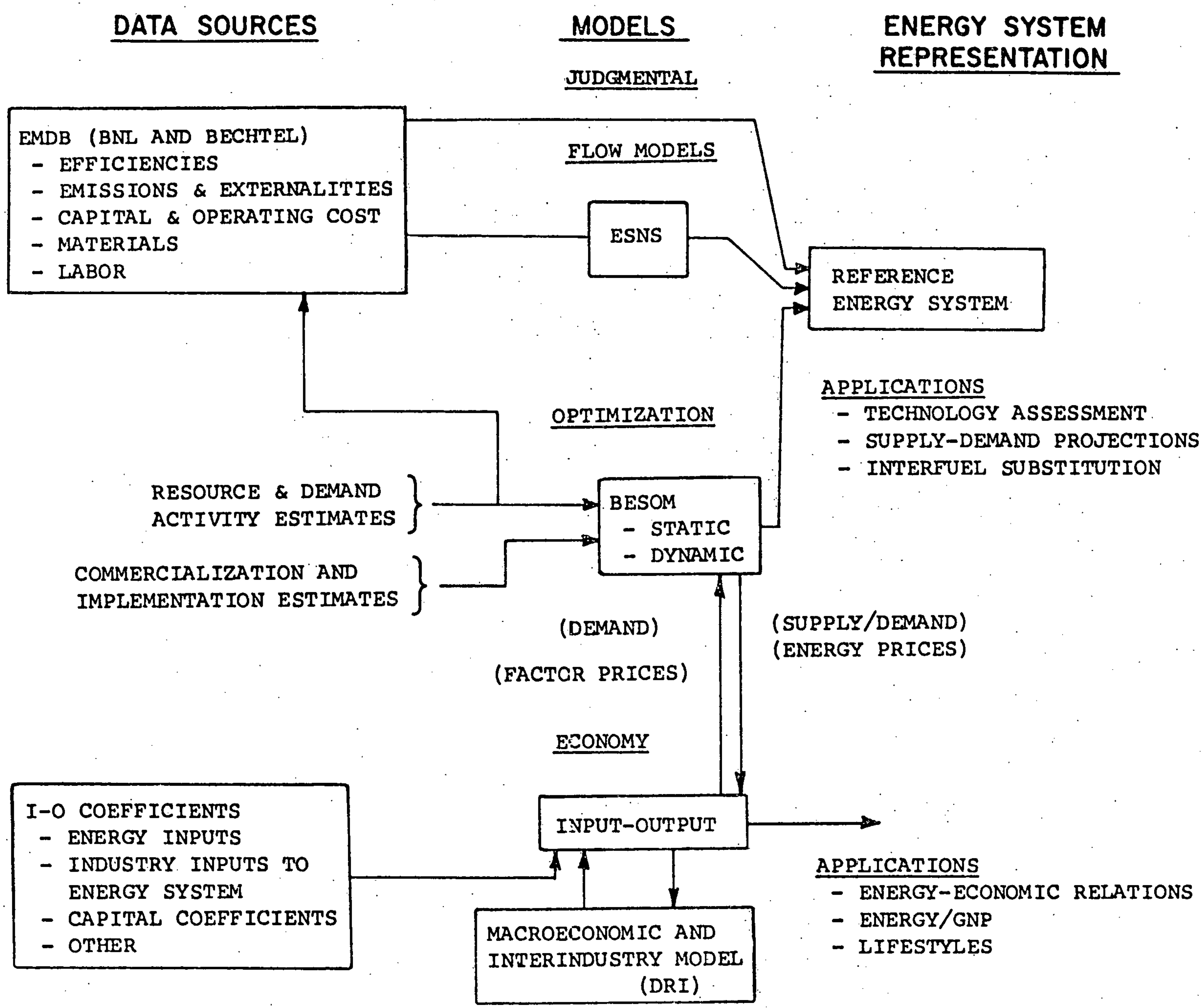

Figure 2 - ERDA Energy System-Economic Models

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REFERENCE ENERGY SYSTEM

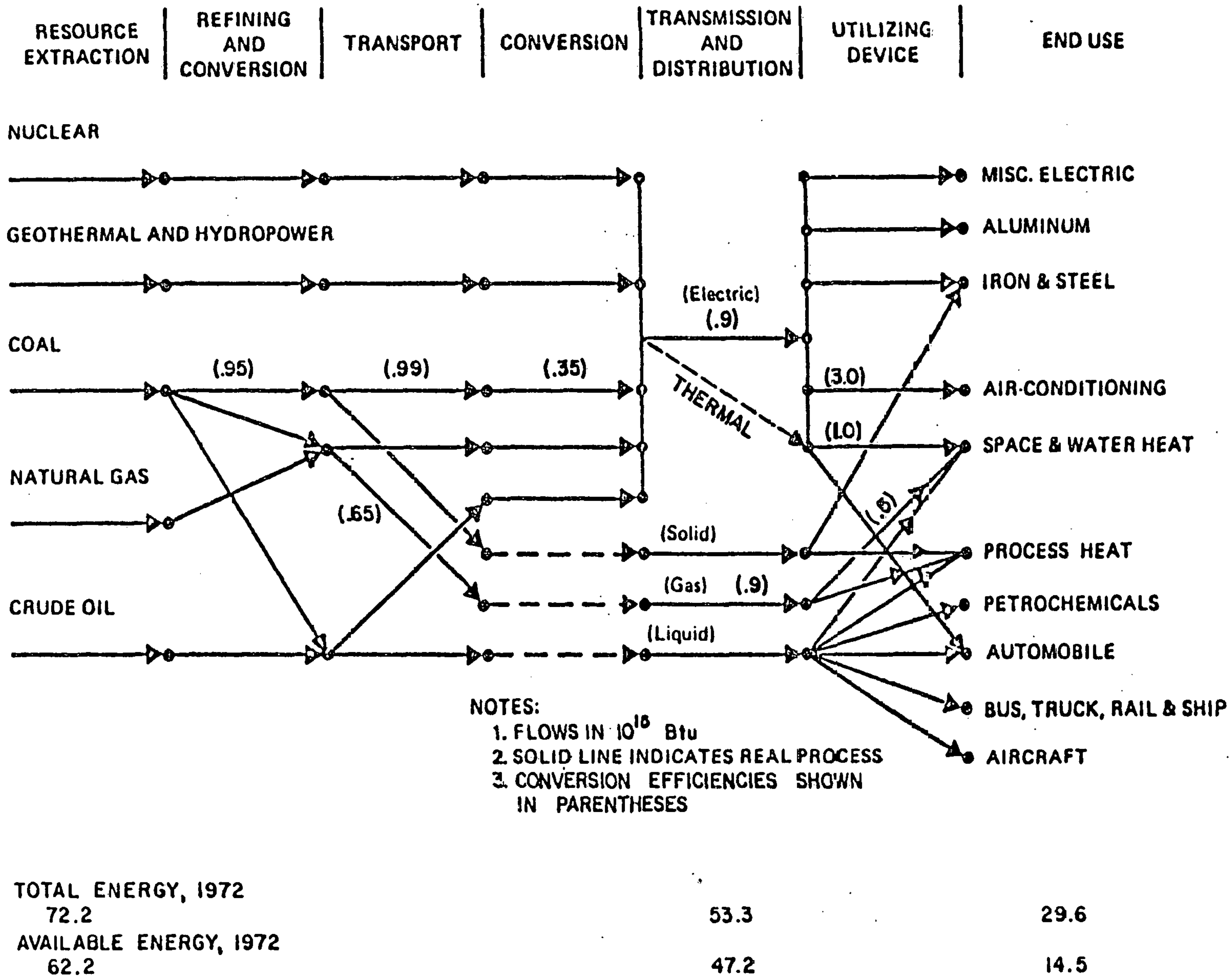

Figure 3 - Reference Energy System

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EMDB PROCESS ELEMENTS (CURRENT TECHNOLOGIES)

• EFFICIENCY FACTORS	MARKET ALLOCATION PRIMARY EFFICIENCY PRIMARY FUEL FRACTIONS ANCILLARY FUEL FRACTIONS ANCILLARY ENERGY ENERGY DEMAND ENERGY DEMAND MEASURE
• WATER EMISSIONS	ACIDS BASES PO_4 NO_4 OTHER DISSOLVED SOLIDS TOTAL DISSOLVED SOLIDS SUSPENDED SOLIDS NON-DEGRADABLE ORGANICS BOD COD THERMAL
• AIR EMISSIONS	PARTICULATES NO_x SO_x HYDROCARBONS CO CO_2 ALDEHYDES, ETC.
• SOLID WASTE & LAND USE	SOLID WASTE LAND
• HEALTH DATA	OCCUPATIONAL DEATHS OCCUPATIONAL INJURIES OCCUPATIONAL MAN-DAYS LOST

Figure 4 - EMDB Process Elements (Current Technologies) (Cont'd)

EMDB PROCESS ELEMENTS
(CONT'D)

• CONSTRUCTION MANPOWER	NON-MANUAL/TECHNICAL NON-MANUAL/NON-TECHNICAL MANUAL/TECHNICAL MANUAL/NON-TECHNICAL
• CONSTRUCTION MATERIALS	WOOD PRODUCTS CHEMICALS AND ALLIED PRODUCTS PETROLEUM PRODUCTS STONE AND CLAY PRODUCTS PRIMARY IRON AND STEEL PRODUCTS PRIMARY NON-FERROUS METALS FABRICATED STRUCTURAL PRODUCTS OTHER FABRICATED PRODUCTS MANY OTHER SELECTED MATERIALS AND EQUIPMENT
• CONSTRUCTION COSTS	TOTAL CAPITAL COST OWNER'S COST MULTIPLIER
• O&M MANPOWER, MATERIALS, COSTS	(SIMILAR LISTS TO THOSE ABOVE FOR CONSTRUCTION)

(ADDITIONAL COEFFICIENT DEFINING TIME-PHASING OF CONSTRUCTION MANPOWER, MATERIALS, AND CAPITAL)

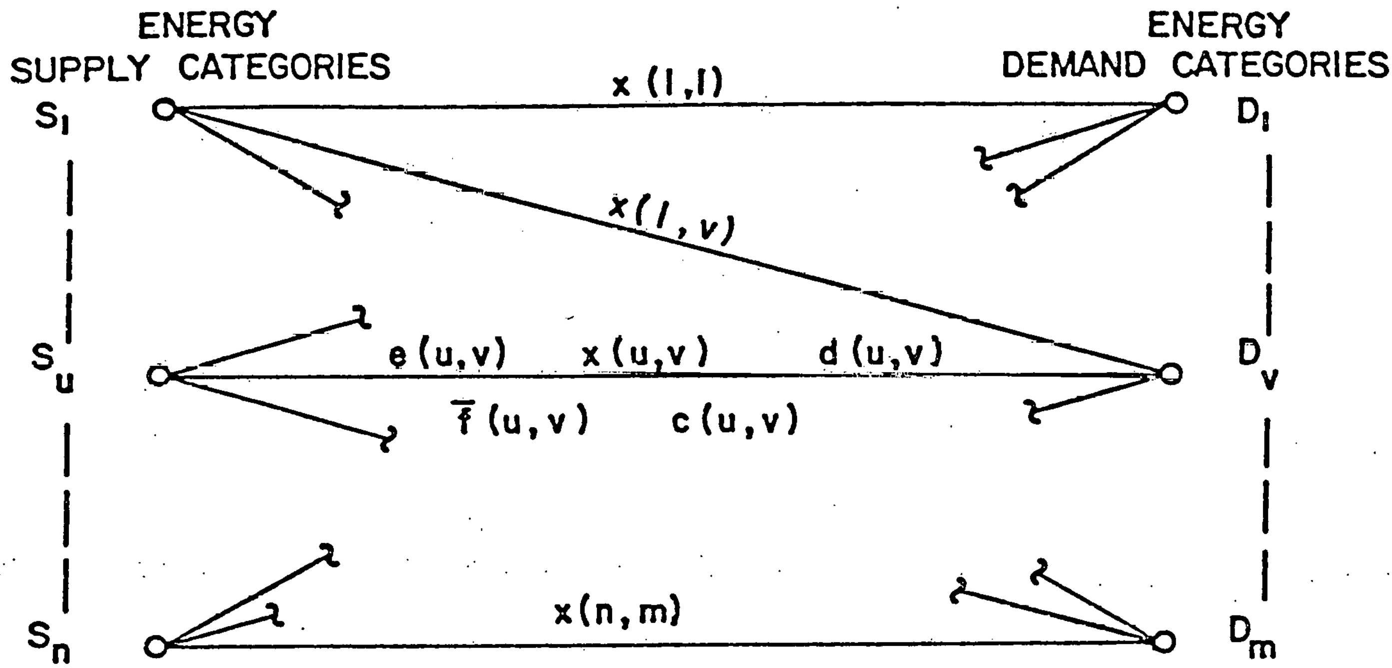
Figure 4 (Cont'd) - EMDB Process Elements

ENERGY MATRIX

SUPPLY CATEGORIES \ DEMAND CATEGORIES	MISC. ELECTRIC BASE LOAD	MISC. ELECTRIC INTERMED. LOAD	MISC. ELECTRIC PEAK LOAD 0.1	ELECTRIC STORAGE	PEAK LOAD 0.2	PEAK LOAD 0.05	CONVERTED RESOURCES	MISC. THERMAL-LOW TEMP.	MISC. THERMAL-INTERMED. TEMP.	MISC. THERMAL-HIGH TEMP.	IRON	PETROCHEMICALS	HEAT PUMP	SPACE HEAT	ENRICHMENT 1	AIR CONDITIONING	WATER HEAT	ENRICHMENT 2	AIR TRANSPORT	TRUCK, BUS	RAIL	AUTOMOBILE	SUPPLY SLACK	SUPPLY CONSTRAINT	MARGINAL VALUE
COAL FIRED STEAM ELECTRIC																									
COAL FIRED STEAM ELECTRIC, COMBINED CYCLE																									
OIL FIRED STEAM ELECTRIC																									
OIL FIRED STEAM ELECTRIC, COMBINED CYCLE																									
OIL FIRED GAS TURBINE																									
GAS FIRED STEAM ELECTRIC																									
TOTAL ENERGY SYSTEMS																									
LIGHT WATER REACTOR																									
LIQUID METAL FAST BREEDER REACTOR																									
HIGH TEMPERATURE GAS-COOLED REACTOR																									
HYDROELECTRIC																									
GEOTHERMAL																									
SOLAR DECENTRALIZED ELECTRIC																									
PUMPED STORAGE																									
FUSION																									
OIL, DOMESTIC																									
OIL, IMPORTED																									
OIL, SHALE																									
NATURAL GAS																									
SYNTHETIC NATURAL GAS FROM OIL																									
METHANE FROM COAL																									
COAL, UNDERGROUND																									
COAL, STRIPMINED																									
HYDROGEN FROM ELECTROLYSIS																									
METHANOL FROM COAL																									
HYDROGEN-COAL																									
COAL LIQUEFACTION																									
DEMAND CONSTRAINT																									
MARGINAL VALUE																									

Figure 5 - Energy Matrix

GRAPHICAL REPRESENTATION OF LINEAR PROGRAMMING MODEL



DEFINITION OF TERMS:

S(u)	SUPPLY CONSTRAINTS, u = 1, n
D(v)	DEMAND CONSTRAINTS, v = 1, m
x (I, J)	QUANTITY OF INTERMEDIATE ENERGY FORM DELIVERED FROM S(u) TO D(v)
e (u, v)	SUPPLY EFFICIENCY FOR ENERGY x (u, v)
d (u, v)	UTILIZATION EFFICIENCY FOR ENERGY x (u, v)
$\overline{f}$ (u, v)	OTHER CONSTRAINT EQUATION COEFFICIENTS FOR VARIABLES x (I, J)
c (u, v)	COST PER UNIT QUANTITY OF ENERGY x (u, v)

Figure 6 - Graphical Representation of Linear Programming Model

EQUATIONS IN THE MODEL

- SUPPLY CONSTRAINT EQUATIONS
- EXOGENOUS DEMAND CONSTRAINT EQUATIONS
- SEASONAL OFF-PEAK CONSTRAINT EQUATIONS

  WEEKLY OFF-PEAK CONSTRAINT EQUATIONS

  PUMPED STORAGE AND SYNTHETIC FUEL BALANCE EQUATION
- TOTAL ENERGY OFF-PEAK CONSTRAINT AND ENERGY BALANCE EQUATIONS
- ENDOGENOUS PEAK ELECTRIC DEMAND CONSTRAINT EQUATION
- ENVIRONMENTAL CONSTRAINT EQUATIONS

  MARKET PENETRATION AND RATIO EQUATIONS
- OBJECTIVE FUNCTION

Figure 7 - Equations in the Model

LINEAR PROGRAMMING MODEL (BESOM OBJECTIVE FUNCTIONS

- ANNUALIZED SYSTEM COST (SUPPLY SIDE)
- ANNUALIZED SYSTEM COST, SUPPLY PLUS END-USE DEVICES
- CAPITAL COST
- ENVIRONMENTAL INDEX
- IMPORTED OIL USE
- TOTAL OIL USE
- RESOURCE USE

Figure 8 - Linear Programming Model (BESOM) Objective Functions

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OUTPUT OF LINEAR PROGRAMMING MODEL (BESOM)

- ACTIVITY LEVELS — REFERENCE ENERGY SYSTEM TRAJECTORIES
- RESOURCE USE
- CAPACITIES AND LOAD FACTORS FOR GENERATING PLANTS
- ENVIRONMENTAL EFFECTS
- SHADOW PRICES

Figure 9 - Output of Linear Programming Model (BESOM)

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INTERINDUSTRY TRANSACTIONS IN THE INTEGRATED MODEL

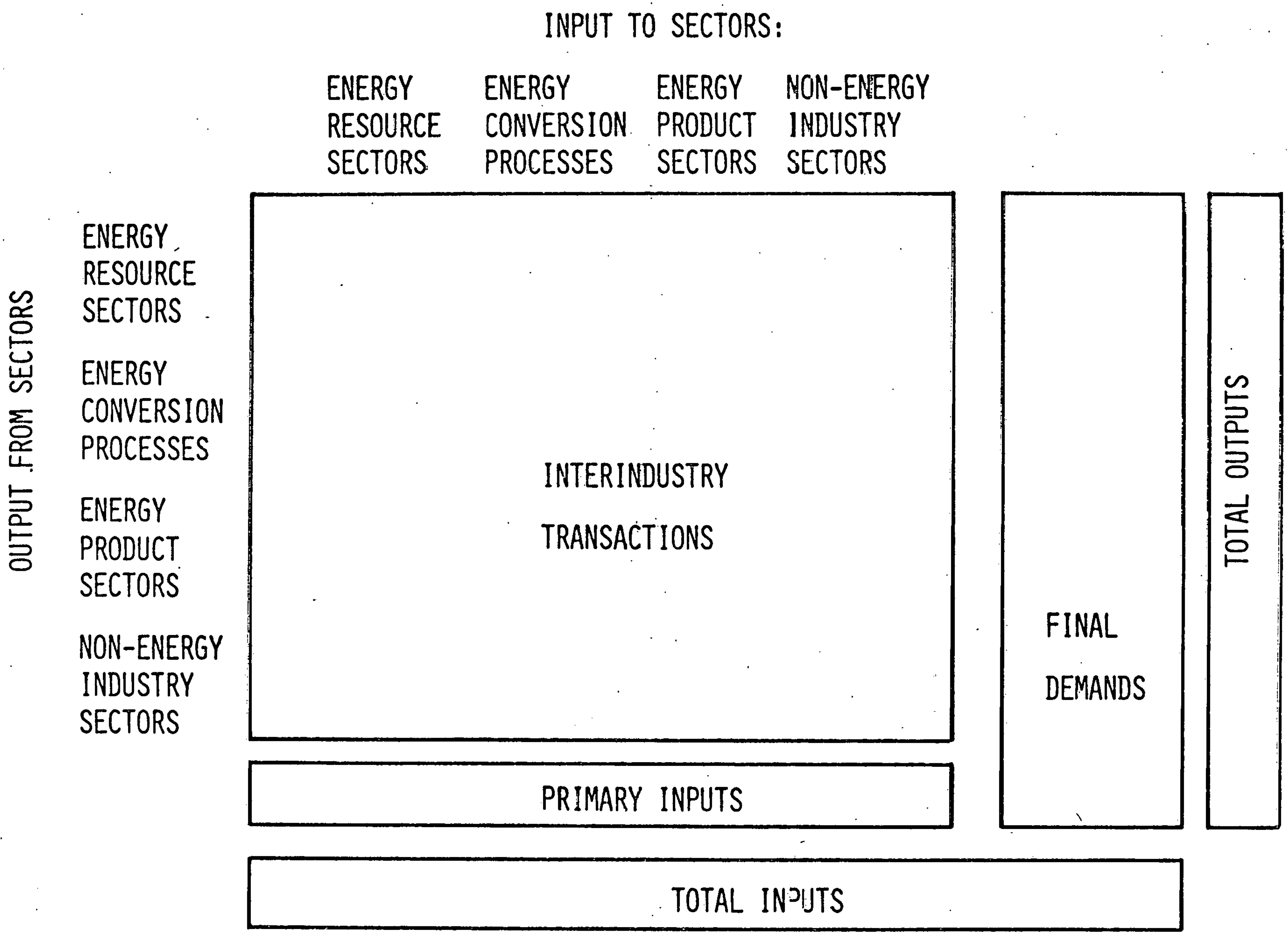

Figure 10 - Interindustry Transactions in the Integrated Model

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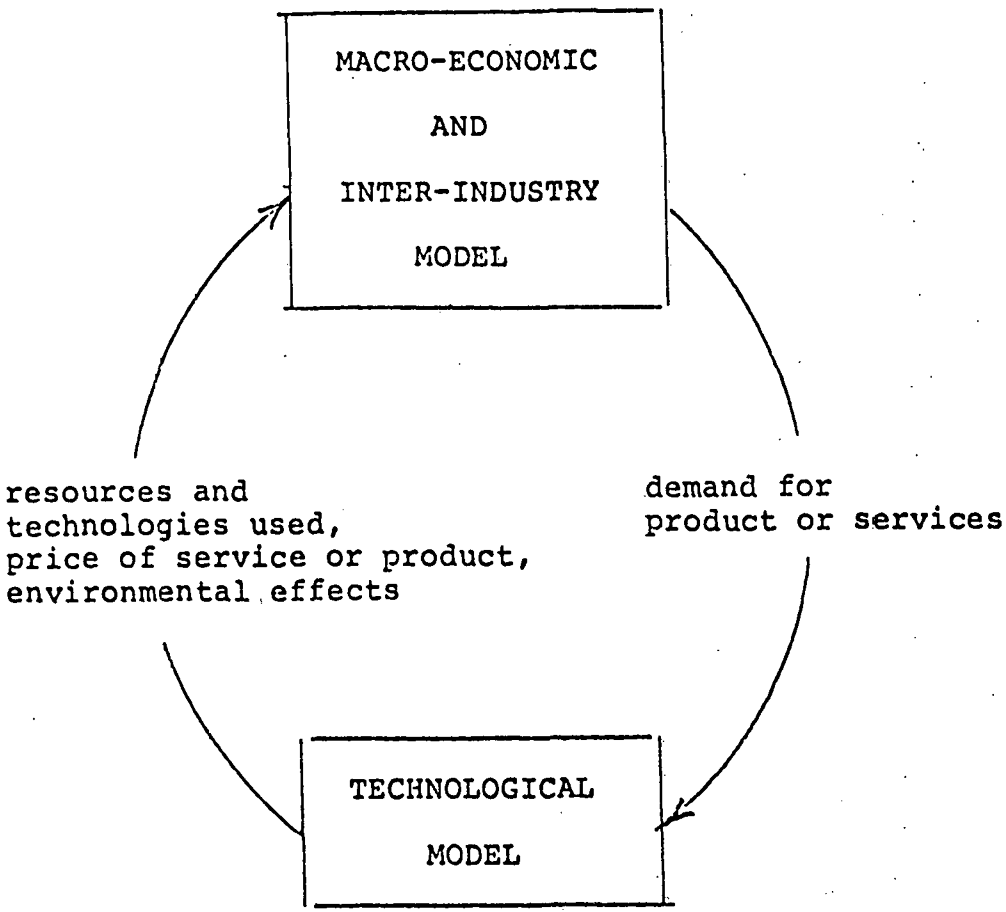

Reflects changes in final demand, GNP, employment, etc. in response to economic and technical policies, resource availability, and technological change.

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

Figure 11 - Flowchart for Technical-Economic Model

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ADVANTAGES OF BNL COMBINED MODEL

- GREATER SECTORAL DETAIL.
- PERMITS ESTIMATION OF INTERFUEL SUBSTITUTION EFFECTS.
- DISTINGUISHES BETWEEN FUNCTIONAL USES OF ENERGY SERVICES.
- INCORPORATES TECHNOLOGICAL ESTIMATES OF POTENTIAL NEW ENERGY SUPPLY, CONVERSION AND END USE ACTIVITIES.
- PERMITS ESTIMATION OF SHADOW PRICES OF FUEL SUPPLIES AND CAPACITIES.

Figure 12 - Advantages of BNL Combined Model

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ADVANTAGES OF DRI COMBINED MODEL

- TIME PHASED, IN WHICH CAPITAL AND LABOR DYNAMICS ARE EXPLICITLY MODELLED, AS WELL AS THE STATIC RELATION OF CAPITAL AND LABOR TO CONSUMPTION AND INVESTMENT.
- SIMULTANEOUSLY ESTIMATES PRICES AND OUTPUTS IN A CONSISTENT FRAMEWORK WHICH IS EXPLICITLY TIED TO NATIONAL INCOME AND PRODUCT ACCOUNTING DEFINITIONS.
- EXPLICITLY INCORPORATES PRODUCTIVITY TRENDS BY SECTOR.
- INCORPORATES INCOME AND PRICE ELASTICITIES, CROSS-CLASSIFIED BY PURCHASING AND PRODUCING SECTORS.
- INCORPORATES TAX, SUBSIDY AND OTHER GOVERNMENT FISCAL VARIABLES.

Figure 13 - Advantages of DRI Combined Model

DJB

APPLICATIONS

- TECHNOLOGY ASSESSMENT
  - — ESTABLISH R&D OBJECTIVES
  - — INTERFUEL SUBSTITUTION
  - — MULTI-OBJECTIVE OPTIMIZATION
- BENEFIT-COST ANALYSIS
- INTERNALLY CONSISTENT ENERGY-ECONOMIC PROJECTIONS
- NET ENERGY ANALYSIS
- AVAILABLE ENERGY ANALYSIS

Figure 14 - Applications

DJB