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ENERGY SYSTEMS STUDIES PROGRAM

ANNUAL REPORT
FISCAL YEAR 1976

M. BELLER, Editor

June 1976

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Prepared for the
OFFICE OF THE ASSISTANT ADMINISTRATOR FOR PLANNING, ANALYSIS AND EVALUATION
UNITED STATES ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
by the
NATIONAL CENTER FOR ANALYSIS OF ENERGY SYSTEMS

MASTER

BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.

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ANNUAL REPORT FISCAL YEAR 1976

M. BELLER, Editor

Contributors

D.J. Behling, Jr.
M. Beller
N. Bhagat
E.A. Cherniavsky
A. Doernberg
M. Fisher
M.D. Goldberg

K.C. Hoffman
J. Lukachinski
P. Newhouse
A.W. Reisman
W.A. Sevian
J. Smith
R.G. Tessmer

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UPTON, NEW YORK 11973

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1.0 INTRODUCTION

This is the fourth annual progress report of the Energy Systems Studies Program that is supported at Brookhaven National Laboratory by the Energy Research and Development Administration (ERDA), Office of the Assistant Administrator for Planning and Analysis. This report is a summary of work performed during fiscal year 1976, describing major activities and objectives. Complete results of the work are described more fully in topical reports issued at appropriate stages in the program.

It should be noted that the work reported in this document is merely a part of the overall effort which is encompassed under Energy Systems Analysis Projects at BNL. Because of the complex interrelationships between technological, economic, social, and environmental factors that influence and characterize energy policy, the energy studies effort at Brookhaven for the Office of Planning and Analysis is now coordinated under the designation of a National Center for Analysis of Energy Systems (NCAES).

The Center is organized within the Department of Applied Science. The Biomedical and Environmental Assessment Division, a joint program between the Medical Department and the Department of Applied Science, is affiliated with the Center. Working groups have been assembled in several areas with specific program responsibilities. These areas are:

1. Policy Analysis
2. Economic Analysis
3. Biomedical and Environmental Assessment
4. Technology Assessment
5. Energy Data and Models

Each of these working groups draws on the collective skills and capabilities of the staff including chemical, electrical, and

mechanical engineers, physicists, chemists, physicians, ecologists, epidemiologists, economists, applied mathematicians, and computer specialists. The staff has long-term experience in energy research and development. Many consultants from industry and the academic community are engaged on a continuing basis and contribute to the program as the need arises.

The programs now included in the Center have provided analysis and support for ERDA, the National Science Foundation Office of Energy R&D Policy, the Office of Science and Technology, and the Council on Environmental Quality. Collaborative work is in progress with the Federal Energy Administration and other Federal and State agencies.

Specific objectives of the National Center for the Analysis of Energy Systems are:

1. To perform energy technology assessments on a continuous basis to support ERDA planning and budget allocation;
2. to perform special regional and national policy studies in support of ERDA objectives;
3. to explore international aspects of energy in relation to technology and policy;
4. to develop improved data bases and analytical methods for use in energy policy analysis and technology assessment;
5. to provide a central focal point for the coordination and integration of energy data and models through collaborative efforts with universities and industry;
6. to maintain current information on the technical, economic, and environmental characteristics of energy technologies for use by ERDA and other agencies engaged in energy technology assessment;
7. to cooperate with and assist other Federal agencies, regional planning and regulatory agencies, universities, and

industry groups in the analysis of special problems of mutual interest and in the dissemination of information and analytical methods; and

8. to provide a site and support facilities for workshops and special task groups assembled to address important topics.

This progress report is intended to cover the areas of the Technology Assessment, Energy Models and Data, and Economic Analysis activities performed in support of Planning and Analysis efforts within ERDA. Within this context, the fiscal year highlights include the following:

1. The publication of a Sourcebook for Energy Assessment which presents an analytical approach broadly applicable to the assessment of energy technologies and policies, and which includes the necessary data and methodology for the assessments.

2. The publication of a study on energy utilization in Sweden, compared to that in the United States, to gain insight into the factors causing differences in energy consumption per capita between the two nations.

3. A benefit/cost study of twenty-eight new technologies, designed to assess problems and cost targets for implementing them into the U.S. energy system.

4. The development of a multi-objective analysis methodology to evaluate the tradeoffs among such parameters as capital cost, imported oil usage, annualized system cost, environmental impact, and resource consumption within a specified scenario for a given time frame.

5. An analysis of the future role of hydrogen in the energy system.

6. The integration of econometric models developed by Data Resources, Inc. with energy-oriented technological linear programming and input-output models developed by Brookhaven, with subsequent application to analysis of the relations among energy, growth, and the economy.

7. Addition to the Energy Model Data Base (EMDB) of a large body of new data on selected new technologies and on manpower, material, and capital costs of current technologies.

8. Completion of an activity-level network for the EMDB flow model and of an interactive capability for the process-level network.

9. Start-up of a program to provide analytic support to ERDA/APA studies of energy-environment interactions.

For these analyses, a series of general planning tools which covers the entire energy system is utilized. Technology Assessment activities employ the Reference Energy System (RES) and Brookhaven Energy System Optimization Model (BESOM) as the primary analytical tools and consider both electric and non-electric energy forms. These models are updated during the course of the program to reflect the most recent data and also contain the flexibility required to permit the needs of each planning task to be addressed. Economic models, such as input-output and a dynamic optimization model, are also available to the program, as are combined models which provide the necessary interface between energy and the economy in the United States.

The activity in the Technology Assessment area is intended to provide a continuous assessment of the state of development and likely impact of new energy technologies and to perform

studies of interfuel substitution. The scope of the assessments includes technologies and processes for all fuels and energy forms and all activities from extraction to end use as indicated on a Reference Energy System (RES). The RES indicates reference or existing technologies with which new technologies must compete. Impacts of new energy technologies are measured against Reference Energy Systems that project the technical structure of the energy system along with costs and environmental impacts through the year 2020. A unique feature of the methodology is the inclusion of the load structure of specific electrical demands and the incorporation of end-use technologies (airconditioners, combustion devices, engines, etc.) at the same level of detail as energy supply technologies, which are frequently a limiting factor in the rate of implementation of alternative energy systems and in energy conservation.

Future scenarios of the implementation of groups of technologies and new resources are developed. The socio-economic and environmental consequences are analyzed in detail and impact analyses are performed.

Comprehensive energy planning and analysis requires detailed study of the economic characteristics of energy technologies and of the relationship of energy to the social and economic structure of the nation. The objective of the Economic Analysis activity is to analyze these relationships ensuring that the technological realities of the energy system are reflected in economic modeling and analysis. Support is provided to the Technology Assessment work in economic analyses used for projections of energy demand and in the analysis of the economics of new technologies.

The Energy Data and Models activity provides a central capability to coordinate and integrate energy data bases and analytical

modeling. Close coordination is maintained with university and industry groups developing data and models of interest to ERDA.

A comprehensive data base, the Energy Model Data Base (EMDB), is maintained at Brookhaven. This data base was developed under the auspices of the Council on Environmental Quality, Energy Research and Development Administration, National Science Foundation, and Environmental Protection Agency. The EMDB is available to governmental, industry, and university groups. The dissemination of the data on energy technologies that are contained in the EMDB provides a uniform and consistent basis for energy policy studies performed by these diverse groups. It also ensures that differences in policy recommendations may be attributed to the viewpoint of the group and not to differences in supporting data obtained from the data base. The Data and Models activity also supports the studies performed within the Center at Brookhaven.

Included in the EMDB are:

- . Technical efficiencies and fuel requirements of 400 energy supply processes and 200 end uses;
- . emissions (air and water), occupational hazards, waste, and costs of individual processes and end uses; and
- . labor, material, and water requirements of supply processes.

Individual data elements (efficiencies, emissions, cost) may be extracted from the data base for each process. This information may be aggregated to provide a summation of elements associated with a given energy trajectory (e.g., coal to iron and steel production), a subsystem (e.g., all uses of coal), or the complete Reference Energy System as projected for some future planning period.

The modeling responsibility includes coordination and integration of energy data and models useful to ERDA, as well as

maintenance and development of the energy system models used in the energy programs at Brookhaven.

While the models that are available to the program are unique and play a major role in the planning tasks, the scope of the tasks is not limited to that which can be accommodated in the models. In addition to the capability within the group directly involved in this program activity, a wide range of technical, economic, biological, medical, and general environmental expertise is available at Brookhaven that may be drawn upon as required for specific planning tasks. The energy and environmental studies at Brookhaven have been interdisciplinary in nature and close interdepartmental working relationships have been established. In addition, a close working relationship is maintained with personnel in the Urban and Policy Sciences Department at the State University of New York at Stony Brook.

There is an increasing interest in the energy systems analysis capabilities at Brookhaven among industrial groups and several discussions and informal cooperative ties have been established.

In addition to the studies performed in support of Planning and Analysis activities, a series of regional studies lend an additional dimension to technology and policy analysis. The Policy Analysis Division of NCAES, supported by the Division of Biomedical and Environmental Research, carries out studies examining the implications of alternative energy futures on a regional basis, with particular emphasis on the Northeast. This study focuses on social, economic, and environmental impacts for this region, thus providing a significant contribution to national energy planning in collaboration with related programs at the ERDA laboratories which are structured to similarly analyze other regions of the U.S.

A nine-region study of present and projected energy use is also being carried out for the Electric Power Research Institute

(EPRI) to add regional definition to analyses of fuel use and technological options available to the electrical utility sector.

Support is also provided to the Office of International Affairs of ERDA. An International Energy Agency (IEA) Systems Analysis program was initiated to evaluate technologies of mutual interest to participating nations for the development of R&D agreements. Brookhaven and Juelich (West Germany) are the designated laboratories where participants carry out these studies. The National Center also collaborates with the Commission of European Communities, working on an energy model for Europe, and is involved with the Workshop on Alternative Energy Strategies (WAES), performing analyses for the U.S. within the context of global energy trade. A WAES seminar was hosted at Brookhaven to familiarize the representatives with energy models and analytical techniques employed by the Center for Analysis of Energy Systems.

2.0 PROGRESS DURING FY 1976

The Energy Systems Studies Program is divided into four major areas:

1. Energy System Model Development
2. Energy-Economic Model Development
3. Technology Assessments and Support
4. Energy Model Data Base Activities

Brief summaries of these areas are provided below, with more detail furnished in following sections of this report.

1. Energy System Model Development

Reference Energy Systems (RES)

Reference Energy Systems through the year 2020 were updated for use in the technology assessments and for inclusion in the Sourcebook. These Systems represent a detailed disaggregation of energy supply and demand projections, reflecting continued economic growth and increased oil prices relative to other energy forms.

Brookhaven Energy System Optimization Model (BESOM)

Cost analyses were performed and consistent capital and operating costs for all supply technologies were developed. These encompassed estimates for mines, wells, and pipelines as well as power plants and synthetics manufacturing plants.

A capital cost row containing those numbers was inserted into the optimization model (BESOM). The row adds up the total installed capital in the year in question, and minimization of this total may be substituted for the usual objective of minimizing annualized supply system cost. This was in fact done during the multiple objective function study.

Annualized capital costs were calculated for end-use devices, and incorporated into the model as an additional row. This row

may be added to the annualized system cost for the supply side when it is desired to minimize overall annualized system cost.

Supply and demand elasticities were inserted in the model for all supply and demand sectors. An algorithm was programmed and debugged that employs the convex simplex method in order to solve the quadratic programming problem that arises when supply and demand curves are piecewise linear.

Environmental coefficients for BESOM were recalculated using the most recent information in the Energy Model Data Base. Emission inventories were compared with those from the Energy Systems Network Simulator for the Sourcebook 1985 Reference Energy System. Since no difference exceeded 0.7%, the data base and model coefficients were demonstrated to be consistent.

Dynamic Model

Work began on establishing a base case for the time horizon 1972-2020 with the time-phased Brookhaven Energy System Optimization Model.

Preliminary investigation of an approach to a sequential version of a time-phased optimization model was begun. In this formulation, decisions about levels of supply technologies and end-use devices are made at each time step, under the constraints that choices may only be made with regard to incremental demand growth and replacement of obsolete facilities.

Coupling with Other Models

Other models and opportunities to combine models were investigated. In particular, the Bechtel coal model was reviewed and liaison was established with personnel at MIT involved in resource modeling.

Regionalization

A plan was developed for an interregional energy optimization model. It consists of linking a number of regions (nine to ten) by imports and exports of fuels.

2. Energy-Economic Model Development

Applications

Two economic analyses were performed for Planning and Analysis. The Interfuel Substitution Study used the combined Input-Output/Linear Programming model to estimate the energy and economic impacts of intensive electrification policy strategies. Upon direction from APA, electrification scenarios were studied rather than coal transformation scenarios. In the second application, the quantity structures of the I-O and LP models were coupled with those of the Data Resources, Inc. (DRI) interindustry and growth models to reproduce exogenously specified energy supply aggregates. Selected model combinations were applied in support of the development of the ERDA plan to analyze the energy and economic effects of two alternative policies involving various ERDA RD&D activities and tax approaches.

Input-Output Model Development

A Capital Matrix for use in the I-O model was estimated on the basis of a coefficient matrix obtained from Battelle-Columbus and the new energy technology vectors obtained under a subcontract to MITRE. Capital-output ratios from this matrix along with estimated sectoral capital depreciation rates were used to endogenously estimate the level of investment in the I-O model, while work on integrating the full capital matrix in either a dynamic I-O or a dynamic LP model, was initiated. A balance of payments adjustment routine was also added to the I-O model. This mechanism related changes in oil and gas imports to changes in non-energy exports and competitive imports via price and income elasticity estimates. The I-O energy supply and energy product

coefficients were adjusted several times on the basis of conceptual changes made by the Center for Advanced Computation at the University of Illinois, and new energy technology input vectors, estimated by MITRE, were added to the model.

Model Coupling-Data Resources, Inc. and BNL

In conjunction with DRI, a plan was developed to completely integrate the pricing and output structures of the BNL input-output and the BNL linear programming model with those of the DRI interindustry and growth models. Implementation of this scheme was initiated. Routines for estimating and inserting modified non-energy sector coefficients and final demands into the BNL I-O model and BNL-determined energy quantities into the DRI interindustry model were programmed. Work on translating energy prices to and from the BNL LP model to the DRI model was delayed as a result of effort devoted to policy analysis for the ERDA 76-1 RD&D plan. An interim procedure for translating energy price/quantity elasticities from the DRI I-O model to the LP model was used in the policy application, however. A computer routine was developed for generating non-energy prices in the BNL linear programming model on the basis of prices determined in the DRI interindustry model.

I-O/LP Coupled Model Development

The capital investment and balance of payments of I-O submodels were integrated with the LP model. These and all improved algorithms and computer routines were developed for integrating these and other submodels into the overall iterative model solution procedure.

I-O/LP Reference Energy System (RES)

An interface for translating energy demands between the RES and the I-O/LP model was estimated.

Data Estimation

Two sets of exogenously specified "Base Case" or "reference" I-O and LP parameters were estimated for the years 1985, 1990, and 2000. One set was based entirely on in-house BNL projections and another on in-house BNL micro projections calibrated with FEA-estimated 1985 and 1990 "calibration case" primary energy supply projections and DRI estimated macro projections of GNP and prices. The in-house detailed non-energy final demand projections were based on Almon and BLS projections; the non-energy I-O coefficients projections on 1985 BLS projections, time trends, and technological coefficient forecasts obtained from International Research and Technology Corporation; the new energy technology I-O coefficients on MITRE estimates; energy supply and energy product coefficients on 1967 historical coefficients and 1967-2000 time trends on time trends calculated using BNL "Sourcebook" projections. The fuel price components of the cost coefficients in the LP model were estimated jointly by BNL and DRI.

Marginal technology coefficients for energy intensive utilizing industries were obtained from Robert Ayres for eventual insertion in a dynamic I-O or LP model.

3. Technology Assessment and Support

Interfuel Substitution Studies

An interfuel substitution study of a coal-intensive strategy was resumed. Recent rapid changes in estimates of the capital costs of coal conversion facilities have necessitated reevaluation of the economics of many of the technologies explored in the study, which will be completed in the Transition Period.

Another interfuel substitution study has begun which examines the role of energy conservation in various consuming sectors and

assesses its impact on allocations of scarce resources. Completion of the draft is anticipated in the Transition Period.

Technology Assessment

The Technology Assessment Group has maintained a continuous effort in monitoring the state-of-the-art of various energy technologies with respect to technical advancement, economic aspects, and potential use in the energy system. This capability was exercised during FY 1976 in various areas, as follows:

1. A Sourcebook for Energy Assessment was prepared, which is a compendium covering all aspects of energy system evaluation. It contains technological, economic and environmental data for present and projected technologies and resources. Additionally, an assessment methodology is presented based on the Reference Energy System format, and six newly-developed Reference Energy Systems are included to the year 2020.

2. A study of the role of hydrogen was prepared at the request of Planning and Analysis, ERDA to provide technological guidelines for a rational R,D and D hydrogen development program, and identify interfaces with other ERDA efforts now in progress.

3. A multi-objective analysis technique was developed and instituted to permit the evaluation of policy and technical change in the energy system in terms of parameters other than system cost. The parameters available for consideration are imported and total oil use, resource use, capital cost, system annual cost, and environmental effects.

Trans-National Comparison

A series of studies comparing energy use between the U.S. and other nations was begun. The first study completed was an

analysis of the U.S. and Sweden, which offers interesting insights on policies and problems encountered for reducing the level of U.S. per capita energy use to that of the Swedish population. Work was initiated on a comparison of energy use in the U.S. and Japan.

Introduction Rates of New Technologies

A study of the rates of commercialization and introduction of new technologies was begun. Its goal is the achievement of more realism in estimating implementation rates for demonstration, commercialization, and large-scale impacts by comparison with past trends in technological change. This will provide an important tool for energy assessment analyses. At present, estimates are based primarily on judgments of the individual analyst.

Special Studies and Assistance

A major fraction of the Technology Assessment Group effort has been expended in special studies for Planning and Analysis. Some of these studies involve an interdisciplinary effort and utilize personnel from other groups within the organization. One example of this work was a benefit-cost analysis of ERDA RD&D programs. Using data collected collaboratively by both ERDA and BNL personnel, system benefits for individual technologies were estimated for specific degrees of implementation, and the benefits discounted to obtain present values. RD&D expenditures for future years were also discounted back to present values. The discounted present values of energy system cost savings and RD&D costs provide the benefit-cost ratios. These may serve as a guide toward allocation of funds, along with other considerations which are also furnished in the analysis. These include resource use, capital expenditures, reduction of oil imports and environmental effects for all the technologies analyzed.

Materials Framework

Development of a Reference Materials System (RMS) continued to provide a framework for analysis of materials systems and their related energy, environmental, and economic factors. This study provides insight into the manner in which energy is used in industry, and is therefore useful as a basis for conservation and fuel substitution analysis. A report will be issued shortly covering renewable resources and selected non-renewable resources that are important to the energy system.

4. Energy Model Data Base Activities

The program in energy data is focused on the care, development, and use of the Energy Model Data Base (EMDB) and of the Energy System Network Simulator (ESNS). The main data base and network model were developed prior to this period but only became available for general use in calendar 1975.

Validation and Management

Continued use of the data base has led to indications of points of weakness or uncertainty in quality of individual coefficient values. Generally, though, the data have held up very well under the scrutiny of a variety of users. Corrections have been made as dictated by the weight of evidence or opinion. Dollar costs remain an area of concern since the time factor is critical and was not clearly defined in the original data base entries. With the help of the Bechtel work (see following), most of the critical energy facility cost factors have been updated to mid-1974 values. In line with work to coordinate aggregated sectoral BESOM and ESNS demand values, the unit energy demands were explored to resolve various industrial sector discrepancies and to bring all demands to a 1972 basis.

Early in the fiscal year the EMDB program, jointly with other BNL programs, purchased an advanced state-of-the-art data

base management system called System 2000 (S2K). The necessary work was done to convert the EMDB files into a S2K-readable format. The replacement of the old ERODE data base management system with S2K has powerfully enhanced the speed and ease with which a user can remotely query the files for information at any level. All of the new data entered into the EMDB during the period were entered in a S2K mode. A user manual is being prepared which will instruct users with all levels of computer background in easily accessing the data base. Report generation features of S2K are being exploited to improve the usability of EMDB-ESNS system output.

Data Base Additions

The new bodies of data developed under contract with the Bechtel Corp. and with Teknekron, Inc. were entered into the EMDB. The Bechtel data increased the supply file content by a substantial factor and provided manpower and material requirements and an expanded cost capability to the data base. The new technology data from Teknekron rounds out the information required for all major new technologies projected for the pre-year 2000 national energy system. Full integration of both data sets into the ESNS network structure was begun.

Regional demand data, at the BESOM level of aggregation, became available late in the period. Preliminary exploration of extension of these data to an EMDB aggregation level through methods to be developed to integrate the BESOM-ESNS demand structures was begun.

ESNS Development

The process-level network version of the ESNS model has been in steady use. An interactive capability was superimposed on this network version of the model, documented, and made available to the user community. A fully interactive activity level network

was developed, documented, and put into general operation. This network is to be integrated at the demand level with the BESOM demands, both at the national average and at the regional levels. As noted above, integration of the new technologies for which data was received into the process-level network was begun, along with the necessary effort required to make material and manpower studies with ESNS possible. Some effort was expended on examining problems associated with regionalization of the model, but no programming was done since the first regional data became available only late in the fiscal year.

User Assistance

Extensive use of the EMDB/ESNS system was made by various programs of the National Center for the Analysis of Energy Systems. Some examples include development of environmental effect parameters for use in the Sourcebook for Energy Assessments, work with the Regional Studies Program on the effects of regional scenarios on the environment, and efforts to integrate an ESNS capability with the energy flow measure work of the Biomedical and Environmental Assessment Division. An example of use of the system in a non-ERDA funded activity in the NCAES was the development of a methodology for states to develop conservation strategy plans in compliance with the Energy Policy and Conservation Act.

A large amount of activity was generated early in the fiscal year under the CEQ and NSF funded program called ENDMAP. Release by the CEQ of a brochure advertising the availability of the EMDB from Brookhaven resulted in a flood of requests for information and for computer tapes. The activity tapered off to a moderate level later in the year and data were supplied to users as requested in a routine fashion.

Following is a list of papers and publications by personnel engaged in these program efforts:

1. Beller, M., Editor. Sourcebook for Energy Assessment. BNL 50483, December 1975.
2. Behling, D. J., Marcuse, W., Swift, M., and Tessmer, R. G. A Two-Level Iterative Model for Estimating Inter-Fuel Substitution Effects. BNL 19863, paper presented at Summer Computer Simulation Conference, San Francisco, July 21-23, 1975.
3. Tessmer, R. G. Interface Equations for 110 Sector Input-Output Model. BNL 20354, July 1975.
4. Beller, M. Reference Energy System Methodology. BNL 21079, presented at 81st National AIChE Meeting, Kansas City, Missouri, April 13, 1976.
5. Tessmer, R. G., and Lukachinski, J. Economy-Wide Impacts of Interfuel Substitution--Substitution of Electricity for Imported Oil. BNL 20493, September 1975.
6. Tessmer, R. G., Hoffman, K. C., Marcuse, W., and Behling, D. J. Coupled Energy System--Economic Models and Strategic Planning. BNL 20120, article to be published in Computers and Operations Research, 1975.
7. Behling, D. J., Dullien, R., and Hudson, E. The Relationship of Energy Growth to Economic Growth Under Alternative Energy Policies. BNL 50500, March 1976.
8. Behling, D. J., and Dullien R. A Combined Linear Programming and Econometric Systems Analysis of the Relation Between Energy, Growth, and the Economy. BNL 21281, to be presented at the 1976 Summer Computer Simulation Conference.
9. Doernberg, A. Comparative Analysis of Energy Use in Sweden and the United States. BNL 20539, September 1975.
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2.1 ENERGY SYSTEM MODEL DEVELOPMENT

2.1.1 Reference Energy Systems

The formulation of Reference Energy Systems (RES) for use in technology assessments for the years 1985, 1990, 2000, and 2020 is based on the escalation of basic energy demands of 25 major activities that comprise the energy system in the U.S. Each activity is described by specific physical units (such as number of households, tons of steel, automobile vehicle miles), and their respective growth rates are documented in Reference 1. While these projected activity levels were not explicitly determined by use of a macroeconomic model, they are based on other estimates which are derived from models incorporating economic assumptions. These baselines thus include some growth curtailment (through energy management and normal replacement towards energy efficient capital stock of presently commercial technologies) as a response to higher fuel prices. Through 1985 the projections represent a detailed disaggregation with minor modification of one of the Project Independence projections developed in 1974. The year 2000 projections reflect a continuation of economic growth and further increase in the price of oil relative to other energy forms.

Several energy-economic models and analytical techniques are under active development at Brookhaven and elsewhere that will advance the state-of-the-art of long-term economic projections. It is anticipated that these will be used in future updates of our baselines to provide a more explicit relationship between energy demands and the state of the economy.

As emphasized above, the Reference Energy Systems (Figures 1 through 6) are expressly designed as baseline projections to allow for perturbation analyses. They thus permit assessments of the impact of new supply technologies or electric conversion

improvements on the total energy system as well as permitting assessment of demand changes. No new energy resources are incorporated into any of the reference years and only two conversion technologies which are not in commercial use at the present time are added: pipeline quality natural gas from coal, and the High Temperature Gas-cooled Reactor (HTGR). The domestic production of oil and natural gas include neither enhanced recovery of oil or natural gas production through stimulation techniques. The RES projections are compared with a number of other forecasts in Figure 7. It should be noted that the RES projection corresponds most closely with the Project Independence \$7/bbl case. This highlights the special nature of the projection as a baseline that assumes little in the way of new technology. Further, it is intended to provide a prudent basis for energy planning; hence the modest conservation response is assumed.

2.1.2 Brookhaven Energy System Optimization Model (BESOM)

Data in the model were updated in two major steps. Capital costs have been changed in accordance with ERDA estimates, and base-load electric generating plant factors are now 0.7 instead of 0.8. Fuel costs are solely associated with "resource" variables. Environmental coefficients were recalculated, based upon data from the Energy Model Data Base. Emission inventories were compared with those obtained by the Energy System Network Simulator. For each effect, the difference was less than 0.7%, demonstrating consistency between coefficients in the linear programming model and the Energy Model Data base.

Equations were added to the model to sum up capital in place and the annualized capital cost of end-use devices. The first equation indicates the investment in energy producing or conversion facilities, while the second reflects the investment in

consuming devices. Capital in place may be minimized as an alternative objective function. The annualized capital cost of end-use devices may be minimized separately, or added to the annualized supply system cost. This was done and the base case was rerun with the new objective function. Allocations were the same, but marginal values changed, indicating that new technologies may be evaluated differently relative to each other with this objective function.

Changes to plant factors of electricity generating capacity may now be made easily through a user program option. The program ensures that the correct coefficients will appear in the objective function, list of plant factors for capacity calculations, and seasonal and daily peaking equations. Changing the peak season and relative durations of summer and winter is now facilitated through another program. The peak season is designated, and two of these three pieces of information must be given: number of winter months, number of summer months, ratio of length of the winter to the length of summer.

Output from BESOM was modified to provide additional information. As an option, one may obtain a printout listing each variable with its non-zero coefficients. The new format is compact and easy to read. A table showing how demands are met by electricity, liquids, gases, coal, hydrogen and heat, now appears at the end of the printout. This is an abbreviated version of the energy matrix which has proved helpful in analysis of model runs and in filling out Reference Energy Systems.

Investigation continued into the use of elasticity representations in BESOM. The objective was to find an algorithm that would allow solution to the problem of finding an equilibrium demand price or supply price point on a piecewise linear curve. This has been shown to be a non-linear programming

problem with quadratic objective function and linear constraints. The algorithm chosen was the convex simplex method. This has the advantage that convergence, as with the simplex method, is virtually guaranteed, i.e., it works in all practical cases. The other advantage is that this algorithm was easy to adjoin to the present in-house simplex code.

The algorithm was debugged, tested in several runs, and shown to perform properly. All demand categories and two supply categories, domestic oil and natural gas, were included. The elasticity assumed was 0.25, and satisfactory test runs were made.

The disadvantage of the algorithm is that it is relatively slow. It took roughly twice as long (30 seconds, compared to 15) to run a case with the elasticity representation as a regular case. This is a characteristic of the convex simplex algorithm, which may oscillate for a long time in the neighborhood of the optimal point before converging to it. In the future, other quadratic programming algorithms may be tried.

BESOM is used widely by other agencies in government, as well as in the industrial and university sectors and by international agencies. Among the users are:

- Los Alamos National Laboratory
- Center for Advanced Computation, University of Illinois
- Institute for Energy Analysis
- Electric Power Research Institute
- Massachusetts Institute of Technology
- Allied Chemical Corporation
- General Electric Company
- Dartmouth College
- TRW Systems Group
- Lawrence Livermore Laboratory
- Air Products & Chemicals, Inc.
- New York University
- United Technologies, Inc.
- Bethlehem Steel Corporation
- Atlantic Richfield Company

(Cont'd)

Users (cont'd)

Lawrence Berkeley Laboratory
Tracor, Inc.
Federal of Swedish Industries
Comision Nacional De Energeticos, Mexico
National Swedish Industrial Board
Electricite De France
Skandinaviska Enskilda Banken, Sweden
British Petroleum Ltd.
Science Museum, Japan
Scandpower A/S, Norway
Secretariat for Future Studies, Sweden
Niels Bohr Institute, Denmark
National Energy Board, Canada
Energiewirtschaftliches Institut an Der Universitat Koln,
Germany
Future Shape of Technology, Netherlands

2.1.3 Dynamic Model

The development of the Dynamic Energy System Optimization Model, partly funded by the Electric Power Research Institute, was continued. The model was reformulated in two different ways. At the same time, work has proceeded on developing the base case for the Dynamic Energy System Optimization Model (DESOM) on which perturbation analyses can be performed. Because inputs to the dynamic model are many and complex, and because results from any model are simply a function of the inputs, the design and implementation of an easy-to-use, self-documenting input format has been emphasized.

Investigation to date has shown that attention is more profitably devoted to this area than to working with alternative solution algorithms. Two choices for solution algorithms for the model are a standard linear programming package and a nested decomposition algorithm. The former are available commercially; much research has gone into maximizing their efficiency and reliability. Nested decomposition algorithms seemed a good possible

alternative, however, since these would take advantage of the special structure of the model. Another advantage of decomposition methods is that the intermediate computations indicate how close the current answer is to the optimal one, so that computation may be halted short of the absolute optimum if desired. This can lead to considerable savings, since convergence tends to be slow in the region of the true optimum with this method.

In order to employ nested decomposition techniques the model had to be reformulated so that it possessed a pure staircase structure. A model is said to have a staircase structure when each equation, except the objective function, contains variables from at most two consecutive time periods. A variable is characterized as belonging to a particular time period according to what it represents. DESOM appeared already to possess a nearly staircase structure, so little difficulty was anticipated in reformulating it. The only changes involved creating cumulative use equations for resources, and redefining capacity transfer between periods. Capacity, e.g., electric generating facilities, refineries, coal gasification plants, built in a given time period, is handed along to subsequent periods until it is retired at the end of its lifetime, a fixed number of periods. In order to conform to the staircase structure requirement, it was necessary to define new variables representing capacities of different ages, and to write equations describing the transfer of the capacity, now one period older, to the next time period.

The capacity transfer equations created an unforeseen inflating of the problem. The original ten-period model had 1325 equations and 2387 variables. The new formulation had 2325 equations and 5814 variables. A test run was made with the new problem using a nested decomposition algorithm developed at the Stanford Systems Optimization Laboratory. There was no significant time

or cost savings in comparison with the use of a standard linear programming package, due to the doubling of each of the dimensions of the problem which obviated the advantages that would otherwise have been anticipated.

To avoid this inflation of problem size, retirement of capacity according to exponential decay was considered. An alternative formulation reduced the size of the staircase problem considerably. However, when a test run was made with the new problem, a numerical instability developed in the algorithm, and no solution was obtained. It was concluded, therefore, that nested decomposition was not a promising method of solving the problem, and reliance has since been placed on standard linear programming packages. Subsequent efforts connected with computer software have concerned problem and report generation, which will be discussed later.

Apart from demonstrating how DESOM could be reformulated with a staircase structure, modelling activities have centered around developing a satisfactory base case.

Meanwhile, quantification of a base case for DESOM has proceeded, using the Energy Technology Sourcebook to provide demand and some supply data. There are 10 periods, each of five years duration. Several initial runs have been made, and inputs have been modified when results seemed unrealistic. Points of departure so far have been natural fossil fuels overconsumption, low synthetics manufacture, low growth in the electrical sector, and all-or-nothing allocations of fuel forms to end-use demands. In addition to using Sourcebook demands, recent efforts have involved coordination with the Modelling Resources Group, headed by Koopmans, for which a number of modelers are making runs with comparable assumptions.

2.1.4 Regionalization

Specific regional analytical capability is obviously becoming a subject of increasing interest. As research, development, and demonstration programs focus on specific technologies, and their implications become clearer on a national scale, their potential implementation requirements and effects must eventually be examined regionally. Obviously, regional climatic variations, environmental standards and problems, access to various fuel forms, and prevailing patterns in energy consumption all will affect the future course of such implementations. Regional transportation options and costs of transmitting present and future energy forms will also strongly influence any selective choices. A regional model will thus permit energy policies to be addressed at a regional level of disaggregation, within the constraints of national policies and supplies. Additionally, it will permit greater sophistication in the analysis of environmental air and water emission data which will be generated at regional levels.

The multi-regional model would consist of a number of regions, probably not more than nine or ten, linked together by imports and exports of fuels. Definition of demand regions is at present expected to conform to that of the census regions, since data for these are readily obtainable. It may be necessary to define different supply regions depending on the fuel forms.

The treatment of each region by itself would be essentially identical to that accorded to the national energy system in BESOM, with differences arising on the supply side. The flows of energy could be depicted in the Reference Energy System format with additional lines indicating shipments of resources or transmission of electricity to or from other regions. The optimal allocation of fuels to demands would be shown by two energy matrices for each region. One energy matrix would show electricity generation and

transmission while the other would show the allocation of fuel forms to demands.

The proposed multi-regional model would be developed in several stages. Such a strategy would expedite the generation of our interregional analytic capabilities and would minimize the data requirements at each stage. Initially, the cost minimizing programming problem would depict periodic national energy systems disaggregated to the level of census regions with no interregional resource or product transfers. All technologies which are currently represented in BESOM would be included. This demonstration version, while not addressing the important issues of optimal interregional energy flows, would nevertheless provide useful information on the cost implications of satisfying regional energy demands with regionally extracted and converted resources and/or resource or product imports. Further, this version would be developed utilizing, with minimal modification, existing software, and multi-regional data.

The second phase of development would involve the incorporation of interregional resource and product flows into the model's structure. This would be accomplished in two sequential tasks. First, the multi-regional transportation options, costs, and capacity constraints for fossil resources and refined products (non-electric) would be specified. Second, the potential for the continuous and optimal interregional exchange of electricity would be represented. As this version of the model is truly multi-regional in scope, regional variations in all costs and conversion or transmission efficiencies would, to the extent possible, be explicitly considered. The successful completion of this stage of development would provide a necessary linkage between our national energy-economic models and existing energy-economic-environmental analytic capabilities at the subregional (state or county) level.

The final phase of development, specific to this model, envisions a further disaggregation of certain components of the national/regional energy system. This would include, but would not be limited to, more detail in the nuclear sector, more varieties of coal, a petroleum refining sub-model (e.g., different types of refineries), and the incorporation of demand elasticities, upward-sloping resource supply curves, and capital cost-capacity scaling factors.

2.2 ENERGY-ECONOMIC MODEL DEVELOPMENT

2.2.1 Energy Input-Output Model

Brookhaven's Energy Input-Output Model combines the Brookhaven Energy System Optimization Model (LP) with an input-output model (I-O) of the nation's economy based on 1967 I-O tables of the Bureau of Economic Analysis, U.S. Department of Commerce. The current version incorporates 110 I-O sectors: 12 energy supply sectors, 8 energy product sectors, and 90 non-energy sectors. The exogenously specified vector of final demand which drives the model is a summation of individual estimates for eight purchasing components of Gross National Product (GNP). Tables listing current model characteristics are presented in Table 1 through 6, and technical descriptions of the model are presented in References 2, 3, and 4. Modifications made in FY 1976 expand its capability and simplify its use.

Linear Program (LP) Modification

The LP portion of the model has been improved and the linkage with the I-O made more compatible. Only one energy product definition in the Energy I-O Model now differs from definitions in References 5 and 1--Ore Reduction Feedstocks. The I-O classifies coke as the only feedstock, with a supply efficiency of 0.809 from underground coal and a demand efficiency of 0.83.

It is probable that one will wish to insert new LP data bases from time-to-time containing different supply and demand efficiencies. This is now much simpler because most the efficiencies needed for interfacing the LP and I-O are keyed directly

to the LP data base. Only two efficiencies have to be entered exogenously-electricity transmission/distribution and pipeline gas transmission/distribution.

Input-Output (I-O) Modifications

Input-output sector 5 has been changed from Solvent Refined Coal to Synthetic Oil from Coal (or Coal Liquefaction), and its output now goes to the Refined Oil Products sector. Solar electric and solar direct thermal technologies are included in the Hydroelectric sector.

The I-O accounts for imports of crude and refined oil in the Import column of the disaggregated vector of final demand (GNP). Although the rest of GNP must be prespecified before running the combined model, the two oil import numbers do not because they are endogenously determined, subject to an upper bound as specified for the imported oil LP equation constraint. The ratio of crude oil imports to refined oil product imports is an exogenously specified parameter. To provide additional flexibility, exports and inventory change of crude and refined can be supplied either by domestic oil or by imports. For all other energy supply sectors, exports and inventory change are met by domestic, and not imported, resources.

Employment data of two types has been assembled for use with the I-O. One is a set of 1967 Labor-Output Coefficients from the Bureau of Labor Statistics, expressed in terms of man-years per 10^{15} Btu or per 10^9 1967 dollars of sectoral output. The second set comprises Lawrence Berkeley Laboratory (LBL) estimates of 1972 U.S. employment (persons employed) for 102 I-O industry sectors, for 422 occupations. This data was furnished to BNL through the assistance of Deane Merrill and Peter Benenson of LBL.

An optional computer subprogram has been written that uses capital-output ratios to estimate capital investment requirements for the planning year being analyzed by the combined model. This value is compared with the assumption for total investment made in the specification of the final demand vector (the summation of gross private fixed capital formation purchases). If the two differ, the numbers on the final demand vector are all changed in the same proportion to obtain a new sum equal to that estimated by the capital coefficients. A compensating adjustment is then made to non-energy personal consumption expenditures (PCE) so that real GNP remains the same. The combined model is rerun with the adjusted final demand vector (say, a reduction in the capital investment component and a compensating increase in the PCE component). This process is repeated a prespecified number of times to obtain convergence between what is specified in the factor of final demand and what the capital coefficients say is required based on total sectoral outputs calculated by the model. The capital/output ratios have been obtained from Just⁽⁶⁾ and Fisher.⁽⁷⁾

A second optional subprogram has been written that makes a balance of payments adjustment between comparative scenarios which have different levels of oil imports. One of the scenarios is first run to a convergent solution using the capital adjustment subprogram, but not the balance of payments subprogram. Data bases are then adjusted for the second scenario, with the exception that crude oil imports and refined oil product imports in the GNP vector of final demand are set at the solution values for the first scenario. The second scenario is solved using both the capital investment and balance of payments subprograms. The solution of the second scenario has a different composition of GNP than the first

(net exports, capital investment and PCE), but the same total GNP in real terms.

The subprogram assumes that foreigners can do four things with, say, the increase in dollars they receive from us for their oil. They can directly buy more goods and services from U.S. firms in the U.S. ($\Delta \text{Exports}_{\text{direct}}$); they can hoard the dollars or buy U.S. financial assets (e.g., stocks and bonds) or buy real assets (e.g., land, buildings, factories), all of which would comprise transfers in U.S. assets ($\Delta \text{U.S. Asset Transfer}$); they can buy more goods and services from U.S. firms located overseas ($\Delta \text{Exports}_{\text{U.S. overseas}}$); or they can spend the dollars to obtain other types of currencies. If they do the latter, the value of the dollar will decrease relative to other currencies, and this dollar devaluation, in turn, will lead to more U.S. exports and less U.S. imports ($\Delta \text{Exports} - \Delta \text{Imports}$) $\$ \text{devaluation}$. Expressed in equation form and in current dollars,

$$\Delta \text{BOP} = \Delta \text{Exports}_{\text{direct}} + \Delta \text{U.S. Asset Transfer} + \Delta \text{Exports}_{\text{U.S. overseas}} + (\Delta \text{Exports} - \Delta \text{Imports}) \$ \text{devaluation}.$$

It is further assumed that asset transfer and purchases from U.S. firms located overseas have negligible effects on GNP structure. Two delta vectors have been prepared which contain estimates, by sector, of the change in exports and in net exports that result respectively from a unit change in foreign direct demand for exports and from a unit change in foreign demand for other currencies which revalues the dollar and changes net exports.

When this subprogram is utilized, the I-O and LP are first run to a convergent solution and the solution value for imported oil compared with the value contained in the initial Y vector. A specified fraction of the increase (decrease) in foreign oil payments is assigned to direct export increase (decrease), using

the delta export vector to disaggregate the change by sector. Another fraction of the increase (decrease) is assigned to an increase (decrease) in net exports using the delta net export vector for disaggregation by sector. The remaining increase (decrease) in oil imports in real terms frees up (takes away) productive resources for (from) the production of other goods and services. It is assumed that all of the compensation is in the production of consumer goods and services; so personal consumption expenditures in the non-energy sectors are increased (decreased) by that amount. A new vector of final demand is thus created which represents a different composition, but not level, of GNP.

It should be noted that the net export changes to final demand are computationally handled in the export column of the disaggregated Y vector. In interpreting a final solution one must therefore add exports (positive numbers) and imports (negative numbers) together and talk only of net exports from sectors other than the crude oil and refined oil products sectors.

Reformulation of the Model

In December 1974 Professor George Dantzig of Stanford University showed that a combined input-output model of the economy and linear programming model of the energy sector could be reduced to a single mathematical programming problem. Although this framework was intended for application to BNL's Energy I-O, two drawbacks prevented its direct use. First, the dummy energy product sectors and the two sets of interface equations in the BNL model were not explicitly treated. Second, Dantzig's mathematical programming equations were presented in a non-linear form.

These two drawbacks have been resolved. All relevant characteristics of the BNL model have been included, and it has been shown that the relevant system of equations can be reduced to a linear mathematical programming problem. The size of the new LP

is equal to the number of equations in the old LP plus the number of energy supply sectors in the I-O (which now is 12), minus the difference in the number of energy demand equations in the LP and the number of energy product sectors in the I-O (which now is 4). This assumes that non-negativity equations will not have to be added for the 110 variables in the I-O (the X's, or total outputs of each sector).

Computer programming of this reformulation is underway. It has been determined that the balance of payments adjustment routine can be handled within the LP structure. Thus, the solution procedure will require iteration only when the capital adjustment routine is used.

2.2.2 Coupling of BNL Models with DRI Models

During Fiscal Year 1976, a coupled version of the Data Resources, Inc. (DRI) and BNL Models was developed and used to analyze impacts of energy taxes and energy research, development, and demonstration expenditures of the economy. The model development aspects of this study are discussed here, while the nature and results of the policy study are discussed under the Planning Applications section.

The following four models are employed in the integrated scheme:

- The Data Resources, Inc. macroeconomic growth model, ⁽⁸⁾ used to specify the long-run trends of consumption and investment, and associated labor and capital requirements, given exogenously specified population and productivity estimates, and aggregate production and utility functions.
- The Data Resources, Inc. interindustry energy model, ⁽⁹⁾ used to estimate the general economic output and price structure of the interaction between energy and the rest of the economy,

given an aggregate consumer utility function and nine sectoral interindustry production functions, all of which are estimated on the basis of past consumer and producer behavioral relations. Aggregate consumption and investment amounts are obtained from the growth model.

- The Brookhaven National Laboratory and University of Illinois input-output model, ⁽²⁾ used to estimate functional end use energy requirements (e.g., space heat and motive power requirements) and detailed labor, capital and material requirements, given an exogenously specified 110-sector order vector of final demands and a 110 by 110 matrix of input-output coefficients, aggregates of which are obtained from the DRI interindustry model. Detailed energy into energy coefficient relations are obtained from a minimum cost solution of a linear programming allocation model of the energy system.

- The Brookhaven National Laboratory linear programming energy system allocation model, ⁽¹⁰⁾ used to estimate physical flows within the energy sector, and the associated least-cost mix of energy supplies and conversion activities, given functional energy end use requirements from the input-output model, prices from the DRI interindustry model, and exogenously specified energy supply amounts and/or supply price schedules.

The two DRI models were integrated into a unified combined DRI model, and several additional routines were added to the previously integrated combined BNL model. Several links between the two combined BNL and DRI models were developed as well.

The general nature of the connections between the DRI Growth and Interindustry Energy Models are illustrated in Figure 8.

In planning applications, the Growth Model is used to estimate the annual nominal and real values of consumption, investment, government spending and net exports over time until the year

2000. For each year, the Interindustry Model is then used to find the sectoral product composition of each of these GNP aggregates, along with associated import, capital, and labor input requirements. By adding all estimated sales to interindustry sectors plus sales to GNP sectors for each sector, total outputs for all sectors are estimated. A 13-order sectoral classification is used in the model: four non-energy interindustry sectors (agriculture, manufacturing, transportation, and services); six energy interindustry sectors (coal, crude petroleum, crude natural gas, refined natural gas, refined petroleum, and electricity) and three value added sectors (imports, capital services, and labor services). For each sector, the interindustry model estimates both prices and quantities.

During Fiscal Year 1976, the following integration scheme was developed.

After using the interindustry model to estimate prices, outputs, and real net exports, a consistency check is run to determine whether the price and quantity of net exports estimated in the Interindustry Model are consistent with those estimates previously used in the Growth Model; if not, the two models are iterated until a convergent solution is reached.

Thus the combined DRI model is a self-contained system for estimating a 13-order vector of prices and outputs over time as well as 13-order vectors of consumption, investment, government spending, exports, and imports. Sectoral prices are estimated on the basis of an exogenously specified aggregate rate of inflation. That is, they specify the degree to which the price of each sector will diverge from the exogenously specified aggregate inflation rate. Since price variables are tied to exogenously specified tax and/or subsidy amounts, the effects of government tax and subsidy changes by sector on prices and output can be estimated.

The connection between the BNL Input-Output and Linear Programming Models is illustrated in Figure 9.

The Input-Output Model is used to estimate the economy-wide energy end-use requirements for eight different energy services (coke, petrochemical feedstocks, motive power, process heat, water heat, space heat, air conditioning, and electric lighting and other all-electric services). These energy service amounts, after some further disaggregation, are then inserted as constraints into the linear programming energy system allocation model, which then is used to estimate the least cost level and mix of energy supplies and energy conversion activities required to meet the specified end-use energy service requirements. From the linear programming solution, energy into energy coefficients are then estimated (e.g., Btu's of coal per Btu of electricity output and Btu's of electricity per Btu of space heat output), along with the Btu amounts of oil and gas imports. After solution of the LP Model, a consistency check is then run to see whether energy into energy coefficients and amounts of oil and gas imports are consistent with those values used initially in the Input-Output Model. If not, the new LP values are inserted in the Input-Output Model and the procedure is continued until a convergent solution is obtained.

The dual version of this combined model was developed so that the model could be used to solve for relative prices as well as output levels. In addition two subroutines were added to the combined model structure. A dynamic capital stock investment subroutine was developed so as to ensure consistency between sectoral capital stock requirements and the level of annual investment in final demand, while a balance of payments subroutine was developed to ensure consistency between the least cost level and mix of energy imports estimated in the LP model, and the level and mix of exports and imports in the I-O final demand sector.

The general nature of the integration scheme being developed is illustrated in Figure 10.

First the flows from the DRI Combined Model to the BNL Combined Model will be described. The DRI Model is used to estimate: (1) aggregate final demands for insertion into the BNL I-O Model (final demand disaggregates are based on BNL forecasts); (2) an aggregate interindustry input-output flow matrix, which is used to estimate aggregate input-output coefficients in the BNL Input-Output Model (disaggregates are based on BNL forecasts); (3) non-energy prices, which are used to estimate the non-energy cost components of energy conversion processes, for insertion in the objective function of the BNL LP Model; and (4) energy demand price elasticities, (obtained by simulation of the combined DRI Model) which are used to estimate changes in functional energy requirements in the BNL I-O Model.

The integration procedure incorporated the following reverse flows from the BNL to the DRI models as follows:

1. DRI annual energy production, export and import rates are controlled to BNL estimated values;
2. the BNL estimated fuel mix specification for the electric utility sector is inserted in the DRI Interindustry Model;
3. the DRI aggregate capital and labor requirements are adjusted for BNL determined incremental capital and labor requirements associated with new energy technologies; and
4. the DRI energy prices are adjusted for BNL estimated energy scarcity values (shadow prices).

During Fiscal Year 1976 all these linkage relationships were developed and all the data transfers required by the linkage relationships were performed manually. Due to the differing levels of aggregation employed in the different models, much ad hoc disaggregation or aggregation is required in the data transfer process.

For current policy applications to date, only the quantity structure of all the models have been integrated, and even with respect to quantities, the iterative solution procedures which have been utilized have not been iterated to full convergence. The current state of the model integration effort is described in detail in Reference 11.

For future policy analyses, Dale Jorgenson and Ed Hudson of DRI have developed a scheme to fully integrate both the pricing and structures of all models. The nature of this scheme is contained in last year's Annual Report. Preliminary testing of this procedure has been programmed and convergent solutions were reached. However, the following two general problems remain. First, the BNL data set is not fully consistent in a definitional sense with that of the DRI Model due to such problems as inconsistent dollar to Btu conversion factors, and differing treatments of secondary product flows. Second, the BNL LP Model generates step functions relating shadow prices to energy quantities, while the DRI Combined Model incorporates only continuous functions. As a result, energy price feedback relations from the BNL to the DRI Model generate either very large or zero changes in the DRI Model solutions. Additional work to smooth out the LP generated step function is thus required.

In addition, David Behling is developing an independent integration scheme which utilizes energy price elasticity data specified with respect to the functional use of energy (space heating, water heating, etc.) as well as with respect to type of energy form (oil, electricity, etc.) and purchasing industry (steel, aluminum, paper, etc.). This scheme is still in the development stage.

While the nature of the eventual linkage and computer relations between the DRI Combined Model and the BNL Combined Model

is still under investigation, much work has been done in aligning the DRI Combined Model for BNL estimated quantity values. The mechanism which performs the alignment of endogenous results with exogenous target values for the DRI models is a generalized version of the linear Newton's method algorithm. There is significant flexibility in the selection of variables for this scheme. Available state and control variables are catalogued in the computer program manual. The user can select the set of state variables which will be adjusted through a user-selected set of control variables until they match a user-specified set of target values. The algorithm is highly efficient. The user is able to keep the amount of computation to the bare minimum by specifying, as input, which off-diagonal elements of the Jacobian need to be computed.

The alignment of the BNL Combined Model for DRI determined magnitudes involves only the adjustment of parameters exogenous to the BNL Combined Model. Currently, this adjustment is done manually.

2.3 TECHNOLOGY ASSESSMENTS AND SUPPORT

2.3.1 Sourcebook for Energy Assessment

A major priority in FY 1976 was the compilation of a "Sourcebook for Energy Assessment,"⁽¹⁾ which has been completed. The purpose of this document was to provide an updated expansion of an earlier study performed in 1972 for the Office of Science and Technology.

Several sections of that earlier document were expanded in this report, particularly those related to resource supplies, environmental emission factors, and the economics of specific energy technologies. The Reference Energy Systems, which provide baselines for perturbation analyses of new technologies, were extensively revised. The Fuel Mix Tables, which provide the coefficients for the demand sector projections used in the Reference Energy Systems were also revised to reflect to a greater extent the levels of user services on which the demands are based.

The perturbation methodology recommended in the Sourcebook was based on modifications to the earlier study to account for problems and deficiencies encountered with it. Specifically, the earlier methodology was designed for large study groups. It proved to be quite cumbersome, particularly for small groups and individual assessors. With this in mind, a simplified methodology was offered in the Sourcebook which can be used by groups of individuals, and which can be performed rapidly using hand calculations.

2.3.2 Interfuel Substitution Studies

A series of studies is in progress to analyze and evaluate the effect of technological change and fuel cost changes on interfuel substitution in the United States energy system.

The first study in this series⁽¹²⁾ focused on the substitution of electric energy for non-electric energy forms in specific end

uses and investigated the feasible range of electrification of the energy system. The influence of growth and saturation of end uses, technological change, and escalation of fuel prices on electrification trends were analyzed and discussed in detail. The intent was to investigate the economic, resource, and environmental consequences of several alternative scenarios rather than to attempt to forecast the most likely course of development of the energy system.

Two successor studies of interest are presently being carried out, and will be described below.

2.3.2.1 Coal Study

A preliminary draft of a study on the intensive use of coal is being extensively revised. This was necessitated by rapid changes in economic estimates of the cost of coal conversion technologies. Since a major tool in the analysis is the Brookhaven Energy System Optimization Model (BESOM), which incorporates technological and economic coefficients for technologies of interest, extensive revision of the cost coefficients was necessary. These revisions have been made, and the study is proceeding. It will evaluate parametrically the alternative options of supplying coal of varying energy contents, and from many regional sources, to a set of demand centers. Thus, such options as conversion to liquids and gases, minemouth vs. urban center electrical generation, and various transportation modes can be evaluated. The parametric analysis based on regional distinctions will then be compared with allocations derived from a minimum cost optimization on a national basis derived from BESOM. Marginal cost information will thus also be obtained, as will environmental emission inventories available from the model.

2.3.2.2 Conservation Study

The analysis of future alternatives in energy supply and demand equilibria utilizing Brookhaven's Energy Systems Optimization Model continues with a study on conservation. The assessment deals exclusively with technical options for conservation and, therefore, underestimates the full potential of a conservation policy that can go beyond the purely technical.

Conservation studies require a greater detail in the demand sectors than is presently in the model and additions are being incorporated. Work on the residential and commercial sectors is essentially complete and the industrial sector has been outlined. Following is a brief description of the work to date.

The demand activities (right hand sides in the linear program) for the residential and commercial sectors (space heat, air conditioning, water heat, and miscellaneous electricity) formerly represented simply by amounts in quadrillion Btu's have been replaced by expressions:

$$\sum_I Y(I) S(I,J) U(I,J)$$

Where $I = 1, 48$ are 48 different residential and commercial buildings and $J = 1, 4$ correspond to demand categories (space heat, water heat, etc.).

$Y(I)$: No. of units of residential space or square footage of commercial space.

$U(I,J)$: Unit demands of energy for 48 types and 4 categories.

$S(I,J)$: Saturations.

The different building types are: single family, multifamily, and mobile homes in four regions grouped into existing structures and new construction (post 1972) for the residential sector. The commercial structures are disaggregated for four regions into existing and new stocks of office, retail, school, and other buildings.

Stocks of existing buildings are decreased along historic demolition rates and the balance is allowed to remain unchanged or to be retrofitted. New construction is assumed to be built according to existing practices (1975), to use the recently approved ASHRAE 90-75 design standards, or to be built with "super" standards.

For all building types unit energy requirements $U(I,J)$ (per residential unit or per square foot of commercial space) in the four demand categories are inserted into the model and multiplied by the saturation levels $S(I,J)$ and the building stock $Y(I)$ to obtain basic energy demands that drive the model in the usual fashion. The $Y(I)$ terms are modeled as variables in the linear program and have costs $D(I,J)$ associated with them. These costs represent the extra outlays required over existing design practices to achieve the improved building performance. These costs are incorporated into the objective function as an additional term:

$$\sum_{JI} D(I,J)S(I,J)Y(I).$$

The mathematical formulation of the model is now:

$$\begin{aligned} \text{Minimize} \quad & \sum_{K=1}^P C(K) X(K) + \sum_{JI} D(I,J)S(I,J)Y(I) \\ \text{Subject to} \quad & \sum_K d(V,K) X(K) - \sum_I Y(I)S(I,J)U(I,J) = 0 \\ & X(K) \geq 0 \\ & Y(I) \geq 0 \end{aligned}$$

for all demand activities that have been disaggregated. All other BESOM constraints remain unchanged.

The assessment is performed by comparing baseline runs for 1985 and 2000 with the case in which conservation is implemented.

The unit demands in all activities in the baseline case correspond to existing 1972 usage; the perturbed cases incorporate the reduced unit demands described above. At this point in the study, conservation runs assume that some 6.5 million homes will be retrofitted by 1985, that half the new construction to 1985 utilizes the new ASHRAE standards and that, after 1985, all new construction complies with them. In addition, 10% of new single family homes have "super" standards after 1985. Preliminary results show a decrease in basic energy demand for all four activities of 7-8% in 1985 and over 15% in the year 2000.

2.3.2.3 Economy-Wide Impacts of Interfuel Substitution

The central question addressed by this study is: What will be the economy-wide impacts of higher oil prices and reduced oil imports over the long run? Within the energy sector, probable impacts have been analyzed in the report, "Interfuel Substitution Study--The Role of Electrification."⁽¹²⁾ Important as they are, effects will be felt outside the energy sector that cannot be investigated with an energy system model alone.

In order to analyze economy-wide effects of changes in energy prices and technology, the Energy Input-Output Model has been used to make two comparisons of the U.S. economy in 1985.⁽¹³⁾ The first comparison (Case A) looks at the question, "What happens if the oil cartel is able to maintain their higher price for oil over the next ten years?" The second comparison (Case B) looks at the question, "Given that higher oil prices do prevail, what are the effects of policies which will cut oil imports drastically by 1985?"

The study finds that 1985 capital investment requirements are about 2% greater than in a Reference Case with low price oil. Most of the increase in capital investment provides greater capacity for the production of coal and electricity as domestic

electric energy is substituted for imported oil. Coal production increases by 31% and electricity production by 16% in Case A. There is also greater investment in exporting industries to pay for the more costly oil imports, and exports increase by 7.5%.

In Case B the study finds that capital investment requirements increase another 3.7% over Case A. Increase in investment of this order would most likely have major impact on capital fund markets. The additional investment occurs at the expense of personal consumption expenditures (standard of living).

Finally, the study shows a marked reallocation of labor to the energy producing areas. Both employment and output are lower in consumer oriented industries such as food and food products, and medical and educational services.

2.3.3 Technology Assessments

A continuing task is the maintenance and updating of information on the status of new energy technologies. A group of individuals is assigned the responsibility for cognizance in specific technological areas which are monitored, and for which data is periodically informally revised.

In support of ERDA's R&D budget planning, a benefit/cost assessment of twenty-eight technologies was performed, relying heavily upon the technological information capability discussed above. The methodology used was to insert a new technology into the energy system using BESOM, and to assess its economic performance against two sets of assumed oil prices in 1985 and 2000. Thus, oil may be replaced or its use reduced by the new technology; additionally, the replaced oil may be reallocated to more efficient and economic use in the optimization by BESOM. The overall system cost change is obtained by comparing the perturbed case (with the new technology in place) with a base case for the reference year, and the change may be positive (a saving) or negative

(an additional cost) to the energy system. The savings or deficit in the years 1985 and 2000 were then plotted, and discounted yearly back to 1975 to obtain the present value (or deficit) to the energy system. Projected R&D expenditures for each year were also discounted back, providing a discounted value of cost, thus permitting estimation of benefit/cost ratios. Marginal values for each technology, as well as resource changes and environmental emissions changes compared to the base cases were also obtained from BESOM. Savings in imported oil were also tabulated.

Although obvious weaknesses are apparent in employing this technique (a major one exists in estimating the degrees of implementation of the technologies in the time frames of interest), it offers the advantages of providing cost targets for economic viability, associated improvements in efficiency which are required, and estimates of the effects upon the energy system in terms of resource requirements, oil imports and environmental consequences.

2.3.4 Reference Materials System

Most of the effort in this area was devoted to gathering data for various materials--both renewable and nonrenewable, and integrating this information into the Reference Material System (RMS). The complete data set for each material includes material flow for a given year, energy, labor, and capital requirements per unit flow of material and environmental impacts associated with each process that a material resource encounters en route to becoming an end use product. This data was integrated in the RMS format in a report to be issued, "Sourcebook for the Assessment of Material Technologies." The list of renewable materials considered in this report is quite exhaustive; additionally, the non-renewable materials include aluminum, iron/steel, and cement/concrete.

The RMS, a comprehensive systems framework for materials policy and analysis, is similar in format to the Reference Energy

System and was developed last year. It is a description of the major components of the material system, specifying all processes (activities) ranging from extraction of resources through their refinement, transportation, and fabrication as well as recycling. A completed RMS is a network representation of this flow of materials from the resource side through all the activities to end use. Each activity represents a technical process or production step that is characterized both by a flow element (Figure 11) and by several data elements (energy, labor, capital, and environmental impacts). See Figure 12 for energy requirements.

In creating the Sourcebook it became quite clear that while strong specialization exists in forest sciences and wood products on the one hand, and agricultural sciences on the other, a broad systems perspective of renewable resources is lacking. Correspondingly, integrated statistical information on resources, material flows, and utilization including associated energy, cost, and environmental aspects, is not readily available in the case of renewables. The situation is somewhat better but still not satisfactory in the case of nonrenewables. Most of the information on renewable materials was obtained in consultation with the members of the "Committee on Renewable Resources for Industrial Materials" (CORRIM), set up under the auspices of the National Academy of Sciences to examine the role of renewable resources in meeting the nation's future needs for materials. Information on nonrenewables was based on various published reports and existing compilations of original data. Although efforts were made to obtain as much information as possible, considerable data gaps, apparent throughout the report, could not be avoided and one purpose of the report has been to identify such gaps. The report also discusses a few case studies of substitution opportunities of nonrenewables by less energy intensive renewables in the area of containers and

packaging, and use of renewables as sources of energy. Specifically, the energy implications of using paper instead of polyethylene plastic for milk containers, woodpulp in place of polystyrene for meat trays and kraft paper bags for polyethylene plastic bags, have been evaluated. In connection with the use of renewables as sources of energy, three options--direct burning, methanol conversion, and synthetic natural gas conversion to obtain direct energy from agricultural/forest waste and residue and municipal waste were explored. Direct burning appears to be the most viable alternative at the present time. Economic guidelines and assumptions, and productivity, which cuts across all the renewable resources, have been discussed in the other sections of the Sourcebook.

2.3.5 Multi-Objective Analysis

The Brookhaven Energy System Optimization Model (BESOM), described previously, is generally used for analysis to determine least dollar cost configurations in energy R&D planning. However, interest is often expressed in terms of other characteristics of the energy system, such as oil imports, capital requirements, environmental considerations, and resource use. Since this model includes coefficients for technologies that relate to each of the major objectives of interest, it is uniquely suited for this type of analysis.

The objectives to be addressed may be weighted and combined in a single objective function to be minimized, or each attribute may be used individually as the objective function while the other attributes are bounded in constraint equations.

The multi-objective analyses were performed for the years 1985 and 2000, allowing all technologies that were included in the ERDA-48⁽⁵⁾ Scenario 5 to compete and be utilized in response to

specific objectives expressed in individual runs. The specific objectives that were addressed in these analyses are:

1. Total annual cost, including amortized capital, fuel, and operating costs.
2. Capital requirements.
3. Resource use.
4. Imported oil requirements.
5. Environmental effects.

The objective function used for environmental effects is a weighted sum of selected emissions. An analysis was done of the ERDA Case 0 emission inventory and weightings were applied reflecting the relative degree of concern over specific emissions (referred to the total level). These weightings were used to combine the several emission equations into a single equation that could be employed as an objective function.

The analysis consisted of three steps:

Step 1: Determination of the unconstrained minimum for each of the five objectives. Given the mix of technologies assumed to be available, a series of runs were made in which each of the objectives was minimized in succession with the other four objectives unconstrained.

Step 2: Trade-off analyses. A series of trade-off analyses were performed to evaluate the relationship between environmental effects and U.S. total annual cost (Figure 11) and resource use vs. total annual cost (Figure 12). In all of these runs the total annual cost was minimized and environmental effects and resource use, respectively, were constrained in decreasing increments from base case values to the absolute minimum value. All trade-off curves indicate a typical knee where small reductions in the constraint cause slight cost increases while further tightening of the constraint causes a more significant cost rise.

It must be kept in mind that the constraints on environmental effects are satisfied simply by the selection of resources and energy conversion technologies from those available.

Step 3: Development of "Best" Combined Case. The "best" combined case was determined by a judgemental process on the basis of the trade-off analyses of Step 2. While it is possible to assign relative weights to each objective and do a single run on that basis it was decided that the judgemental approach was more reasonable.

Priority was given to the environment--cost trade-off as a starting point. On this basis, total cost, oil use, and environmental effects are constrained close to (but above) their absolute minima and the capital cost is minimized. Total resource use is unconstrained, since it is not a major point of concern compared to the other parameters.

The results of the "best" cases are shown in Table 7 compared to the minimum cost cases normally obtained with BESOM. It is seen that total cost and oil use are quite similar in the comparison, and that resource use, although unconstrained, is not markedly different. Environmental quality improves, and capital requirements are appreciably lowered.

2.3.6 Sweden Study

The report "Comparative Analysis of Energy Use in Sweden and the United States" was completed during the past fiscal year.

Following are the major conclusions that can be drawn from the study:

1. The largest difference between the two countries' per capita energy use is in the transportation sector (accounting for 16% of the 37% per capita differential). The household and commercial sectors do not manifest large differences, but consideration

of the longer winters in Sweden indicates higher levels of insulation there. The industrial comparison suffered from data availability on energy use per unit of product, but it suggests better efficiencies in Sweden.

2. The major technological factors that are involved in the U.S.-Sweden comparison are:

- . District heating: one out of five homes in Sweden is heated by hot water distributed from a central plant; moreover, one half of this heat is co-generated with electricity.
- . Hydroelectricity: 70% of Sweden's electricity is generated by hydropower, contributing to lower costs; it is also the likely determinant in the higher relative level of electricity in Swedish industry, compared to the U.S.

3. The analysis performed focused on direct energy consumption. It is necessary to give more consideration to the energy embodied in import and export goods to make a more meaningful comparison between the relative intensities of energy consumption of two countries. Sweden's industrial mix is more concentrated than that of the U.S., making the embodied energy analysis more important. They accomplish "savings" by producing internally less petrochemicals and aluminum than the U.S. and by importing a sizeable fraction of petroleum as refined product. On the other hand they produce large amounts of steel, pulp and machinery for exports, which are all energy intensive. These effects are more diluted in the U.S. because of a better match between domestic consumption and domestic production.

4. An attempt to achieve a 40% reduction in U.S. consumption by the year 2000 (the strategy outlined draws on Swedish consumption patterns) proved to be quite difficult and would have

significant effects on life-styles and the structure of the U.S. economy. Alternative strategies which may have lesser effects should be considered. These may involve lower consumption objectives or may attempt to achieve the same objectives used here by different means.

5. The difficulties in labeling an energy use pattern as affecting lifestyle to a certain or an uncertain degree is underscored when attempting to define transferability of foreign energy usage experiences to the U.S. The study does not tackle this question directly, but suggests that Swedish energy use patterns would have a significant effect on lifestyle in the U.S. How close the U.S. can come to breach the gap in per capita energy consumption depends almost entirely on the policy-maker's definition of what is a lifestyle change as opposed to an efficiency change. The obvious example is the switch from large automobiles to small ones.

6. More detailed analysis is needed to determine comparisons of lifestyle and standard of living. Relative GNP, corrected for exchange rate devaluations and inflation, is not a satisfactory measure.

2.3.7 Hydrogen Assessment

A preliminary report was submitted of an assessment of the role of hydrogen in the energy system. The report provides detailed information on present and possible future uses of hydrogen, and is intended to indicate the areas and priorities for hydrogen production and utilization where Federal R&D funding is desirable.

Major conclusions of the study are:

- Present and future hydrogen use is significant in the industrial sector.
- Hydrogen can prove of value as a supplement to natural gas; its use by electrical utilities for peak-shaving is strongly dependent upon fuel cell development.

- Hydrogen may play a limited role in transportation systems.

- R&D emphasis should be placed primarily on production improvements from both coal and water electrolysis, with lesser emphasis on production from thermochemical or biomass sources.

- A need exists for research on safe, lower pressure storage systems for stationary and transportation applications.

2.4 ECONOMIC ANALYSES

2.4.1 Energy and Economic Growth Analysis

During Fiscal Year 1976 a semi-integrated BNL-DRI modeling framework was used to estimate the energy, economic and environmental impacts of two policy proposals against a Base Case set of economic and energy projections for the years 1985, 1990, and 2000. (11)

The two policy proposals were as follows:

1. The introduction of RD&D initiated energy supply and end use conversion technologies to expand domestic energy supply and to improve the efficiency and flexibility of its use.

2. The imposition of taxes and tariffs on petroleum and natural gas to reduce demand for these primary energy sources.

Targets for the amounts of imports of oil and gas were specified by ERDA as follows:

- 10% (or less) of total U.S. energy consumption in 1985,
- 8% (or less) of total U.S. energy consumption in 1990,
- 5% (or less) of total U.S. energy consumption in 2000.

The purpose of the analysis was to first identify the degree to which the introduction of new energy technologies and/or the imposition of energy taxes could reduce oil and gas imports to the target levels, and second to estimate the effects of these policies on the economy and the environment. These economic and environmental effects are thus a measure of the costs associated with meeting the import targets. The benefits of these policies, in the form of increased economic and political security, were not measured.

Summary of Results

Total reliance on new technology to meet 1985 and 1990 import targets would require rates of new technology implementation

exceeding the feasible rates of implementation presented in Case V, "combination" scenario for 1985 and 2000 in ERDA-48. Achievement of the import target specified for 2000 via ERDA-48 specified amounts of new technology is possible. However, full voluntary commercial implementation of the feasible amounts would require either considerable government subsidies and/or reductions from currently estimated future costs.

The formal analysis of the economic and environmental impacts of new technology implementation was thus limited to new technology amounts in 2000 which would not require subsidies and/or cost reductions,* and amounts which would not exceed ERDA-48 specified feasible amounts. For all years, demand was reduced via endogenously determined price increases so as to fill the gap between supply expansion induced by the new technology and the import reduction targets. Equilibrium between energy demand and supply was achieved by letting energy prices be determined endogenously. This combination of price and RD&D policies is referred to as Case A1, "Tariff plus RD&D," or "combined demand reduction and domestic supply expansion" policy. An alternative policy, Case A2, or demand reductions via higher energy prices alone (through import tariffs and taxes), was also considered. This is referred to as Policy A2, or "Tariff only" Policy.

Table 8 lists, for both policy cases, the tax, tariff and RD&D supply expansion amounts which would be required to achieve the import targets. In the absence of RD&D, a tax and tariff on both oil and gas of 48% in 1985, rising to 230% in 2000, would be required to achieve energy self-sufficiency. Under Policy A1, a smaller tax and tariff would be required, as the amounts of RD&D-generated new energy supplies coming on line increases from 4.9 quads in 1985 to 22.0 quads in 2000.

*The small amount of solar electric generating capacity included in 2000 would require a subsidy.

For Policy A1, the separate contributions of increased taxes and of specific RD&D technologies in achieving the required amount of oil and gas import reduction are listed in Table 9. Together, these measures reduce Base Case amounts of oil and gas imports by 8.4 quads in 1985, 16.2 quads in 1990, and 40.1 quads in 2000. The contribution of demand reduction to total import reduction increases from 40% in 1985 to 50% in 2000, with RD&D additional domestic supplies accounting for the remainder. RD&D contributes to import reductions both by providing new types of domestic primary supplies and by increasing the use of existing coal and uranium supplies either directly by the introduction of new coal and uranium conversion technologies, or indirectly via increased electrification of transportation and heating. In Policy A2, by assumption, the entire import reduction is achieved via higher energy taxes and reduced demands.

The economic effects of the two policy alternatives are summarized in Tables 10 and 11. In estimating the economic effects, it was assumed that taxes and prices would rise gradually over time and that these price increases would be anticipated by energy purchasers, thus giving them sufficient time to adjust their production and consumption practices. The primary economic effect of either policy is a reduction in the rate of real income growth from an average of about 4.0% per annum between 1985 and 2000 expected without the energy policies, to 3.9% under the combined supply expansion-demand restriction policy (Tax plus RD&D) or to 3.7% under the demand reduction policy.

The overall balance sheet of the effects of both policies was presented in terms of the five criteria adopted by ERDA. On this basis, the policies can be described as follows:

1. Maintenance of national security: both policies are equally efficient in meeting this goal, since both achieve the desired reduction of U.S. dependence on imported oil and gas.

2. Maintenance of economic well-being: both policies would reduce future levels of real income and output by small amounts. The annual rate of increase of GNP in any future year would decline at most by 0.3 percentage points, from 4.0% to 3.7% per annum. Policy A1 would reduce future income levels less than Policy A2 as long as the present value of all future RD&D expenditures required by Policy A1 does not exceed \$178.4 billion (1975 dollars).

Under both policies the distribution of income shifts slightly toward greater relative income returns to capital than to labor. To the extent that capital income is distributed more unequally than labor income, annual growth rates in the real income of lower income classes might decline at most by another 0.1 percentage point, from 4.0% per annum Base Case rate, to, at the lowest, a 3.6% per annum rate.

As long as either of these policies was implemented gradually and continuously over time as assumed, there would not be any sectoral transition costs associated with either policy. Under both policies, output and labor requirements for each sector continue to increase in absolute size over time--only relative magnitudes change.

Under either policy, however, the aggregate unemployment rate would increase in all future years from the assumed Base Case rate to 4.8%. On the average over the three years considered, Policy A1 causes the unemployment rate to increase from 4.8 to 5.2%, Policy A2 from 4.8 to 5.35%. The largest yearly increase is 0.70 percentage points for Policy A2 in 1990.

The fact that both policies give rise to some unemployment of both labor and capital has a positive aspect, however, in that additional government policies designed to stimulate aggregate demand could also be employed along with Policy A1 or Policy A2

so as to eliminate the unemployment, and increase real consumption, and income at the same time. However, such expansion policies would further increase both the rate of inflation and energy requirements.

Assuming just Policy A1 or A2 is pursued, the increase in energy prices results in a slight increase in the estimated annual rate of inflation between 1985 and 2000 of about 0.15 percentage points for A1 and 0.30 percentage points for A2.

3. Maintenance of desired lifestyles: under both policies, household consumption rates of all goods and services would decrease only slightly from Base Case rates. However, a large portion of the decrease would be concentrated on reduction in energy purchases. Under both policies, fuel purchases for transportation activities decrease sharply relative to Base Case amounts. Improvements in the efficiency of fuel use would absorb much of the potential impact of the reduction in fuel purchases, however. The annual growth rate of private automobile vehicle-miles would decline from the 3.7% per annum Base Case growth rate to 2.2% per annum under A1 and 2.1% per annum under A2. These lower growth rates still permit yearly increases in per capita automobile travel.

Unlike transportation, Policy A2 would lead to much greater decreases in Base Case rates of household and commercial energy consumption rates for space heating and air conditioning than would Policy A1. Under A2, moderate decreases in inhabitable space per dwelling unit would probably be required, barring significant improvements in the efficiency of heating and air conditioning units, while under A1, energy limitations would not necessarily preclude consumer preferences for detached single family dwelling units.

4. Promotion of world stability: both policies would assure continued U.S. economic growth and prosperity. Also under both policies, the U.S. would absorb reduced amounts of foreign oil and gas supplies. This would increase the income and welfare of other oil and gas importing nations, while reducing the income and welfare of oil exporting nations. Policy A1 would have the additional effect of increasing the world-wide availability of new energy technologies.

5. Protection of environmental quality: both policies would reduce those environmental impacts associated with energy consumption activities, particularly hydrocarbon emissions resulting from automobile travel. On the other hand, both policies would increase those harmful land and radiation effects associated with greater domestic coal and nuclear production rates, while decreasing oil import related oil spills. On balance, Policy A2 would lead to less environmental damage than Policy A1, since under A2, both domestic energy production and energy consumption rates are smaller than those associated with Policy A1.

2.4.2 Nuclear Moratorium Study

Support was given to ERDA in their analysis of the effects of a nuclear moratorium on the U.S., in terms of implications for the economy and energy system. The work performed was of a very brief nature, covering a period of one month, and relied primarily upon other studies in this area and discussions with electric utility personnel.

2.5 ENERGY MODEL DATA BASE ACTIVITIES

2.5.1 Data Base and Flow Model Development

2.5.1.1 Validation and Management Improvements

During fiscal year 1976, the Energy Model Data Base (EMDB) has evolved into a more readily accessible and easily manageable source of information on the United States energy system. Initially, the EMDB was available either to experienced users of the ERODE program via computer tape or by a manual search through a huge computer printout. With the adaptation of System 2000 (S2K), a commercial data base management system purchased by the Department of Applied Science early in the fiscal year, the manageability and accessibility of the EMDB has been significantly enhanced. A new facility of on-line EMDB data updating and retrieval, for all classes of users, was realized through the creation of the S2K data base files SUPPLY, UTILIZ, and DOCUMENT. The first two files contain the supply and utilization process data with reference and footnote numbers for each data element. The third file contains all the textual documentation, indexed by the reference or footnote number.

After an initial familiarization period with the S2K package, Energy and Environmental Data Group (E/EDG) personnel proceeded to convert the ERODE files into S2K input format. Before this conversion was accomplished, an acceptable logical structure of the EMDB was formulated. Figure 13 illustrates the logical structure that was formulated to best describe one "logical entry" (i.e., an energy system process) of the data base and Figure 14 illustrates the logical structure of the corresponding textual documentation file, DOCUMENT. This data structure was then translated into S2K data base definitions. Alternate S2K definitions were attempted before the decision was made to adopt the current ones. Then an ERODE-to-S2K conversion program was written and

utilized to create the proper input for the three S2K files. Two alternative methods of loading data into an S2K data base were compared and the more efficient method was used to load the files. Due to the size of the SUPPLY file, it was decided to load this file in a number of separate computer runs. This procedure permitted the correction of minor errors found during the loading operation. As the files were loaded onto the on-line disk devices, they were also backed-up onto magnetic tape in case of unanticipated computer or disk storage problems. This procedure is vital to ensure the ability to reload information.

In order to assure that the data had been properly loaded, several verification procedures were performed. Various sorts of retrieval operations were used for this purpose. Many of these retrievals proved to be very useful. For example, a sorted list of process names, with corresponding identification numbers (id#) was generated (see Tables 12 and 13) from the SUPPLY and UTILIZ files. This list has become a useful summary of the contents of the EMDB and has been disseminated to interested persons. As the data base grows, this list will be regenerated. In addition, a tally of the names (or CTI numbers) of the data elements found in the EMDB was generated. Unfortunately it was found to be difficult to generate a list of unique element names along with their corresponding card-type-identifier (CTI) number and units. This would be a very useful list and effort will be expended to investigate this problem.

Listings of references and of footnotes, sorted by the identification number (Reference # or Footnote #), have been obtained from the DOCUMENT file. Because the documentation was extracted from the SUPPLY and UTILIZATION ERODE files in parallel, some duplicate references were found and subsequently removed. In addition the large task of updating a majority of the footnotes,

which had not been done for the ERODE files, was done directly on the S2K file DOCUMENT.

The next task to be performed on the S2K files was report generation. Problems were encountered when using the S2K Report Writer Feature, and the present version of S2K has its limitations. Future versions may alleviate some of these problems. In the meantime, certain reports could be generated. For each file a report has been created that includes all data elements for each process. Under current limitations, either reference numbers or footnote numbers can be printed for each data element, but not both. Work is underway to create a complete listing of the EMDB, including documentation, similar to the "people-readable" output generated by ERODE.

To allow a user (technical or non-technical) to obtain information from the EMDB quickly and easily, a list of on-line retrieval statements was compiled. Each of these statements actually represents a series of S2K commands that perform a specific retrieval function. This set of complex commands has been grouped together and given a functional name to make retrievals as simple as possible. One such statement allows the user to retrieve all the data elements for a given process (see Figure 15). The only information the user must supply is the id number of the process. (This can be found in the list of processes in Tables 12 and 13.) The use of this statement will cause the following information to be printed for each data element:

1. element name
2. value
3. units
4. quality # measure
5. last modification date, if any

The list of retrieval statements will be expanded as needs occur.

2.5.1.2 Data Base Additions

New Technologies

An accurate description of the United States energy system requires data for emerging as well as current supply technologies. It thus became necessary for the E/EDG to obtain data pertaining to these new energy technologies so that the current EMDB could be expanded. A new EMDB file has been created to contain new technology processes. These data were obtained from two sources outside of Brookhaven--Hittman Associates and Teknekron, Inc.

Initially data pertaining to some of the emerging technologies was prepared by Hittman Associates as a continuation of their original work which culminated in the EMDB Supply and Utilization files. Data were collected for the following new technologies:

1. Low Btu gasification of coal
2. High Btu gasification of coal
3. Oil shale
4. Fluidized bed boiler combustion of coal
5. Solvent refined coal
6. Coal liquefaction

Following the collection of the data by Hittman, E/EDG personnel converted the data into machine-readable form. This process has been completed and a new ERODE file for New Technologies (NTEC) has been created.

Data for additional new technologies were required to supplement the work done by Hittman. Subsequently, Teknekron, Inc. of Berkeley, California was selected to collect the data on the following additional new technologies:

1. Methanol production from coal
2. The nuclear fuel cycle
3. Advanced fission reactors
4. Solar energy conversion

5. Geothermal energy conversion

6. Solid waste conversion

By the middle of the fiscal year, the individual processes had been selected and researched. The data was put into machine readable form and submitted to the E/EDG by Teknekron along with their Draft Final Report. Corrections were noted in these and sent to Teknekron. A final report, "Pollutant Releases, Resource Requirements, Costs and Efficiencies of Selected New Energy Technologies,"⁽¹⁴⁾ was released in March and a final computer tape received. E/EDG personnel used this tape to create another ERODE file (NTEC). A "people-readable" listing of this file was made available for distribution to NCAES personnel.

Because of a slight overlap between the processes contained in the data collected by Hittman and by Teknekron, efforts to combine the two ERODE files (NTEC) have been temporarily postponed. When it has been decided which of the duplicate processes contains "better" data, the two files will be combined and converted into one S2K file--NEWTECH. The documentation for these processes (references and footnotes) will be added to the S2K file DOCUMENT. At this point four S2K files will comprise the EMDB: SUPPLY, UTILIZ, NEWTECH, and DOCUMENT.

Manpower, Materials, and Capital Coefficients

Initially the data elements related to each EMDB process were of the following types only:

1. efficiency factors,
2. emission factors,
3. health data, and
4. annual cost data.

Needs for other sets of data have arisen from other constituent parts of the NCAES. Once such data set--manpower, materials, and capital requirements for the large facilities involved in the

energy system--was found to have been quantified by the Bechtel Corporation of San Francisco. It was decided that this work would constitute a worthwhile addition to the EMDB, and Bechtel was contracted to reconstitute a large part of their data into the EMDB format, with full documentation. In March, a preliminary data tape was received from Bechtel along with a sample listing of their final report. Errors were noted and a list of them was sent to Bechtel. The final data tape arrived in mid-May.

In its present form, the ERODE program can handle only 190 data elements per process. The addition of the Bechtel data to existing supply processes caused this limit to be exceeded, so a slight modification to the data format was necessary. For this reason the present version of ERODE cannot handle the new Bechtel data, even for verification purposes. Instead, the S2K conversion program was used to perform some initial data verification. The Bechtel data will be added to the current S2K SUPPLY file, and the new documentation will be added to the S2K file DOCUMENT.

Because the Bechtel data had been substantially developed prior to its preparation for the EMDB, some of the facility definitions did not have corresponding processes in the EMDB. As a result, additional processes were added to the SUPPLY file. Although Bechtel has gathered the manpower, materials, and capital coefficients for the new technology process, funding has thus far only allowed the data for the current fossil energy supply system to be prepared for inclusion in the EMDB.

2.5.1.3 ESNS Development

At the onset of its availability during the previous fiscal year (FY 1975), the Energy System Network Simulator (ESNS) has served the Energy Model Data Base Program as the primary interface between the EMDB and those who have needs for energy system analysis at the level of disaggregation provided by the EMDB,

namely the energy system processes that possess both national and regional supply components. ESNS has continued to serve in this capacity in the current reporting period, with enhancements and new developments being made to this capability to further its continued utilization as a tool for energy analysis.

The basic nature of the ESNS model was briefly investigated. Although it has become regarded variously as an "energy flow" model, a "simulation" model, or an "accounting" model, it was found formally to be an exact analogy to input-output models, with the I-O matrix entries consisting of expressions involving the primary efficiency and ancillary energy requirements for a particular process. The I-O formulation might need to be adopted to permit future enhancements, since it handles explicitly certain coefficients that appear only implicitly in ESNS. However, it is felt that the present "energy flow" formulation, which derives directly from the Reference Energy System (RES), is not only adequate for present needs but easier, for a user anxious for results, to interpret.

A need was recognized during the continuing model development for an activity-level ESNS-type model. For such a model, the detail of the process-level version of ESNS requires aggregation so that a single activity (e.g., for the distribution of petroleum products) appears in place of all processes common to the activity. Such a model has been developed, and a brief description of the energy network chosen for this model follows.

This activity-level network has tentatively adopted, for consistency, the end use demand structure currently available in the RES. For the supply portion of the network, the fossil fuel supply processes appearing in the ESNS process network were aggregated for the activity-level network. The result is a representation for this particular set of processes containing somewhat

greater detail than the RES. The remainder of the supply processes are taken directly from the RES. The future accessibility of new data for all new technology supply processes (e.g., from the Teknekron effort particularly for the nuclear fuel cycle) will permit their aggregation and assimilation by a redefinition of the activity-level network structure. In fact, the design of the accessibility packages (software) permits such definitions with ease.

In order to provide an initial activity-level capability, the present ESNS software was used, with the process-level network being replaced by its more aggregated counterpart. After some minor software changes, the capability was fully debugged. The more improved, fully interactive version (ESS) that permits direct interface with the computational algorithms and the imposition of supply constraints was also made available.

Several versions of the basic process-level ESNS model were generated. Analysis of the Reference Energy Systems appearing in the Sourcebook for Energy Assessment can be performed with ESNSRES, where the process level network was rearranged using the perturbation analysis capability to reflect the standard RES structure. A separate data bank was also created and is available for use. All emissions totals appearing in the Sourcebook were generated with ESNSRES.

Two regional variants of the ESNS capability were created through requests from personnel in the Regional Energy Studies Program with the Center. ESNSMD exists for the state of Maryland, and ESNSME for the state of Maine. Both variants rely primarily on EMDB data for environmental coefficients, but as for ESNSRES, separate data banks were created for each case. The state of Maryland plans to use their version of ESNS as a monitoring tool for the implementation and measurement of various state-level

conservation strategies. Aid in the construction of both these packages was provided by EMDB Program personnel.

At the request of the head of the Biomedical and Environmental Assessment Division within the Center, the ESNS model was employed to generate results using inputs from the ETA model of Professor Alan Manne at Harvard University for a nuclear moratorium study. Using the ESNS perturbation capability, both a base case year 2000 scenario and a nuclear moratorium scenario were developed to conform to the aggregated levels of energy production provided by the ETA model.

Since the controlled data set in the EMDB supply file does not contain specific breakdowns of primary fuel losses by kind (physical, process) and ancillary fuel requirements by fuel type, the ESNS data file (containing only national average processes) was updated to include such losses. The overall supply system efficiency that is computed during each ESNS controlled technology run now reflects all primary fuel losses.

2.5.1.4 Interactive Program Developments

A capability has been developed to permit interactive access to the energy system model ESNS via remote computer terminals. Up to the present, energy analysts with minimal backgrounds in computers were unable to utilize ESNS without the assistance of an experienced programmer. The available package permits a user having a minimum amount of programming expertise to directly input a prepared analysis at a remote teletype. All inputs are properly formatted. Then the analysis is automatically dispatched to the central computer for execution, and the results when generated are routed to the user's terminal where they can be directly inspected. The data file created and formatted is saved by the program for alternate access in the standard batch mode. The

interactive computer code that enables all of the above has been named Interactive Remote Access to ESNS (IRATE).

IRATE functions in a conversational manner by requesting input data in response to language-type queries. All data, as it is entered at the teletype, is formatted and subsequently written onto a separately accessible file. When execution of the data query portion of the program is completed, a catalog function automatically stores the created file. This file is available for additional modifications using standard editing commands. Then, a routing function automatically dispatches the ESNS code along with the interactively created perturbation analysis data to the central computer for batch-type execution. Informative messages are generated by IRATE at the user's terminal giving the progress of the analysis. When a result is generated, the output file is cataloged and made available at the user's terminal. All these formatting and management activities are transparent to the user.

Access to the IRATE/ESNS package has been provided through the Brookhaven National Laboratory Central Scientific Computing Facility (CSCF). Installed at the CSCF are two CDC 6600 computers and a CDC 7600 computer. One of the 6600's is assigned to running the BROOKHAVEN remote access system. It is through this system that access to ESNS through IRATE is provided, using any remote terminal with a provision for telephone linkup. With the IRATE package's query capabilities, it is possible to perform all analyses via a user's terminal using only a few of the many available INTERCOM commands. Outputs generated may be paged at the terminal and useful portions of the results saved on paper. However, complete output files may be quite lengthy depending upon certain user-selected options. If copies of such output are required, a separate printer of the type associated with a batch station installation is needed.

2.5.2 Support Operations

EMDB program personnel have provided considerable amounts of user assistance in the following categories:

1. in-house aid to BNL staff in the use of the EMDB/ESNS system,
2. general information on available capabilities to interested Federal, State, and local agencies, public and private corporations and private individuals,
3. detailed instruction in the use of and access of the EMDB and ESNS model to federal and state agencies and their contractors, and
4. analysis of specific policy or technological alternatives for groups outside BNL.

Funding for the user assistance categories listed above comes from two sources: a) (1) was funded by ERDA-APA, and b) (2), (3), and (4) were funded under a Council on Environmental Quality (CEQ) program, ENDMAP (Energy Data and Modeling Assistance Program). Some of the analyses under (4) were funded by separate interagency contracts. Under these programs the EMDB/ESNS system has been maintained at the Brookhaven Central Scientific Computing Facility in a form which allows individual investigators to access these capabilities via a remote terminal and to perform analytic studies. Demonstrations and training have also been provided to those requiring assistance in developing their skills in the use of the system.

User Information and Training

Early in the fiscal year, a brochure was released by the CEQ specifying the availability of the EMDB from Brookhaven National Laboratory. In preparation for the CEQ announcement, EMDB personnel demonstrated for CEQ Chairman, Russell Peterson, a user-oriented interactive computer program (IMP) which allowed access

to the EMDB/ESNS system by persons unfamiliar with computers and computer language. The publicity surrounding the release of a "user-oriented" energy data base and flow model generated a very large number of mail and phone inquiries. A substantial amount of time from EMDB personnel was required: a) to fulfill and tabulate in a log book these requests for information, b) to prepare and send out magnetic tapes containing EMDB data and/or the ESNS code and files, and c) to train interested users in the details of computer access to the EMDB/ESNS system. To aid in this last effort, a summary brochure of the BNL remote access user language (INTERCOM) was prepared and entitled "Access to the Energy System Network Simulator (ESNS) via Remote Computer Terminals." Interested users received computer accounts under ENDMAP funding, allowing free access to the system.

Among the users assigned computer accounts during FY 1975, two deserve special comment. Personnel from the energy policy offices of both Maryland and Maine spent substantial time acquainting themselves with the Reference Energy System (RES) method upon which the ESNS model is patterned. Both states prepared their own Reference Energy System (RES) by modification of the structure and basic data of the ESNS model. Both Maine and Maryland feel that the ESNS model is an excellent tool to use in policy analysis on a state level. It is anticipated that many more states will prepare Reference Energy Systems for use with the ESNS flow model.

During FY 1975 a third set of solar analyses were performed for Robert Stromberg of SANDIA, Albuquerque, New Mexico, a follow-up on analyses performed during FY 1974. For these analyses, 1% of the total energy consumption in the residential sector was provided by solar energy instead of energy based on fossil fuel combustion, and the change in the energy-related residuals produced

was noted. In additional trajectories, the energy needed to supply the various types of residential demand, e.g., space heat, water heat, and electric use, was replaced singly and in combination by solar. The results were also used as part of a solar energy study by the Office of Technology Assessment, United States Congress.

A list of EMDB/ESNS users is outlined below:

•Federal

Council on Environmental Quality
Transportation System Center, DOT
Office of Technology Assessment, U.S. Congress
Federal Power Commission
Office of Energy Conservation and Environment, FEA
National Research Center, EPA (NC)
Resource and Land Investigation Program, USGS
Government Accounting Office

•Laboratories

Argonne National Laboratory
Los Alamos Scientific Laboratory
Lawrence Berkeley Laboratory
Institute for Energy Analysis, Oak Ridge
Lewis Research Center, NASA
Battelle Memorial Institute

•State and University

Office of Energy Policy, Maryland
Office of Energy Resources, Maine
Governor's Energy Council, Pennsylvania
Institute of Mining and Minerals, University of Kentucky

•Regional

Northwest Energy Policy Project
Kentuckiana Interregional Planning and Development Agency
Bonneville Power Administration

•Private

Electric Power Research Institute
Energy Studies Group, SOHIO
Systems Group, TRW
Radian Corporation

Bechtel Power Corporation
International Research and Technology, Inc.
Midwest Research Institute
NUS Corporation

• International

International Institute for Applied Systems Analysis, Austria
Economic Commission for Europe, Switzerland
AB Atomenergi, Sweden
Energy Group, National Sciences Council, Ireland
Reactor Centrum Petten, Netherlands

2.5.3 Energy-Environment Support Capability

The EMDB/ESNS system is particularly well suited to the examination of the relative effect of alternative energy technologies and policy strategies on the production of environmental residuals. The coefficients for residuals are specific for each technological process in the energy system. In addition, the extensive documentation available in the EMDB that describes the assumptions behind the development of each coefficient allows recalculation of a given coefficient if the assumptions are to be changed for a specific analysis.

During FY 1976, the EMDB/ESNS system was used in four contexts where the primary emphasis was on the generation of residuals in order to assess the relative impact of energy production and consumption on the environment.

1. Sourcebook for Energy Assessment

The primary source for the emissions coefficients listed in the Sourcebook is the Energy Model Data Base. The national emission inventories, presented for the reference years 1972, 1980, 1985, 1990, 2000, and 2020 were obtained by the use of the ESNS flow model. These inventories provided an index to future environmental energy-related effects.

2. Northeast Perspectives Study

The aim of the Northeast Perspectives Study was to examine the northeast regional energy system with the intent of estimating

the effects that various technological, policy, and socio-economic factors could have on the development of the energy system between now and the year 2000. The methodology used began with the classification of the region's present and projected energy supplies and demands in terms of the four basic energy "carriers," i.e., liquids, gases, electricity, and coal. Alternative projections were developed for both supply and demand, taking into account many possible future socioeconomic conditions and policy decisions. Several reasonable "matched" scenarios (supplies approximately equalling the demands) were selected and studied in detail.

The environmental consequences of the selected scenarios were examined by first dividing the energy carriers into specific fuels and their associated uses. Five air emissions were chosen for study: particulates, nitrogen oxides, sulphur oxides, carbon monoxides, and hydrocarbons. These emissions originate from such point sources as oil and coal-fired steam electric plants, coking facilities and industrial facilities, as well as from such dispersed sources as residential and commercial space and water heat, and ground transportation.

The source of coefficients for the selected air emissions was the Energy Model Data Base. Because the EMDB is fully documented with respect to the methods employed to calculate the coefficients it contains, it was possible to recalculate coefficients to reflect the specific composition of fuels consumed in the Northeast, as well as the projected level of environmental controls. The modified coefficients were then used to create inventories for each selected scenario. These inventories allowed the ranking of the selected scenarios with respect to their relative environmental impacts.

The environmental analysis for the northeast perspectives study is documented in a report "Health and Environmental Impacts of Alternative Energy Futures for the Northeast." (15)

3. State Conservation Program

The Energy Policy and Conservation Act, EPCA, provides for a program to be administered by each state in which the State and Federal Governments may work together to develop state energy conservation plans. Although the program is optional and flexible, if a state wishes to participate it must a) submit a plan which includes consideration of five specific areas related to buildings and transportation, and b) provide for an overall reduction in energy consumption by 1980 of at least 5%.

Under funding from the Federal Energy Agency, the Energy Policy Analysis Division examined the environmental impact of the five mandated conservation areas and considered the accumulated energy savings which would result from their application on a national basis.

The base case 1980 target year was represented by the projections contained in the Brookhaven 1980 Reference Energy System. The environmental impacts were calculated from EMDB data by use of the ESNS flow model. Overall energy savings resulting from application of the proposed conservation measures were calculated by the model as well as savings in each fuel type and energy sector.

The conclusions of this assessment were that the State Conservation Program of EPCA will result in beneficial environmental impacts, especially with regard to areas impacted by the combustion of natural gas and oil to provide space and water heat, automobile fuel, and peak period electricity.

To assist the states in calculating the local impact of each alternative, work sheets were prepared which incorporated the results of the analysis as calculated by the ESNS flow model. This

study is documented in a report "Final Assessment of the Environmental Impacts of the State Energy Conservation Program." (16)

4. Regional Environmental Impacts of Emerging Technologies

Beginning April 1, 1976, support was extended to the EMDB by the Office of Environmental Analysis, ERDA/APA to examine the impact of evolving technologies on the environment. The purpose of this program is twofold: to develop an analytic methodology which will provide ERDA with quantified input describing the environmental consequences of proposed policies on a meaningful regional level, and to examine the significant environmental constraints to development of specific technologies.

The program is being developed in several stages. The first stage has been the collection of information concerning existing regional data sources and environmental assessment methodologies. Some thought has been given to defining critical areas of analysis, toward which future work should be directed. In addition, however, where existing tools can be utilized or quickly modified to give additional insight on the energy-environmental interaction, this is noted and incorporated into the overall plan of development.

It has been decided to approach the problems of environmental analysis by selecting a specific problem for study, for example, the synthetic fuels scenario of ERDA-48, and then defining the questions which need to be asked and answered in order to assess this energy strategy in particular, helping to point the way toward formulation of energy policy questions in general.

Four task areas have been outlined:

Task 1 - Define the questions which need to be asked in order to assess environmental impacts of alternate development policies.

Task 2 - Use existing tools, modified where appropriate, to assess the questions raised in Task 1. Begin to develop new assessment tools to fill in the gaps where existing tools are inadequate or lacking.

Task 3 - Determine a systematic approach to routine solution of energy-environment problems.

Task 4 - Define a new problem and iterate again through Tasks 2 and 3. It is hoped that with additional experience each new analysis will yield a more sophisticated approach to energy environmental interactions.

As work proceeds through the four task areas, efforts toward solving environmental assessment problems will be coordinated with similar undertakings in progress in other groups which comprise the National Center for the Analysis of Energy Systems.

3.0 PROGRAM PLAN FOR FY 1977

The program plan for FY 77 includes the following tasks organized by major areas.

AREA 1 - ENERGY DATA:

Task 1.1 Data Base Management and Validation

The implementation of the System 2000 Data Base Management System provides an array of useful functions which will be exploited to provide services which will be useful for all areas of the Energy Systems Studies Program. The two main functions involve: 1) report generation for use with the output for all modeling activities, in association with the developing graphics capability (Task 1.4), and 2) unified integration of the basic data and input data, technological, economic, environmental, demand, etc., used by the various program models. A critical look will be taken at all supply data in the Energy Model Data Base (EMDB) in order to update from the present nominal 1970 base year. Cost information will be updated to 1975 dollars while efficiency and environmental data will be updated to the best currently available estimates. Demands and allocations will be updated to 1972 or 1974, whichever is most feasible. The new data integrated into the EMDB on new technologies and on manpower, material and costs will continue to be considered for validity and utility. Any collaborative data work initiated with the Bechtel Corporation under Planning and Analysis guidance will be carried out under this task.

A systematic approach to validation and updating of the data base will be designed and implemented.

It is anticipated that future work will involve the development of increased regional supply and demand detail in the data base. In preparation for that activity a plan will be

developed for the structure and manipulation of regional data in the EMDB.

Task 1.2 User Assistance

Interaction with the full user community of the Energy Data Program tools is a vital necessity for well-directed growth and for control of the quality of the analytic capability provided by the data support. Work will continue with the staff of all components of the National Center for the Analysis of Energy Systems, with Planning and Analysis staff, and with staff of other ERDA divisions in order to make the full ERDA/ESNS system available to them. This will be integrated with the separately funded ENDMAP work so that feedback from the entire user community can be used for data validation and for data and model improvement. Updating of the User Manual, as required, and routine answering of requests for EMDB tapes and listings will be included in this task.

Task 1.3 Energy System Network Simulator (ESNS) Development

The inclusion of all the new data entered into the EMDB, particularly the manpower and material elements, into the ESNS structure will be completed. Regionalization of the activity-level ESNS to track the evolving regionalization of the BESOM will be carried out. Integration of the information richness of ESNS output with the evolving graphics capability (Task 1.4) will be done in order to improve the impact of results obtained with the model. Addition of a nodal capacity constraint option will be made to the model.

Task 1.4 Graphics Capability Development

A graphics capability will be developed which will allow the production of graphical representations of the outputs of

all Brookhaven energy models. This will include not only x-y plots, histograms, pie charts, etc., but also automatic creation of Reference Energy Systems. Interfacing to the Brookhaven models will be accomplished and documented, and instruction in use will be provided for all involved personnel. The capability will also be made available to outside users of the EMDB/ESNS system.

AREA 2 - ENERGY MODELS:

Task 2.1 Brookhaven Energy System Optimization Model (BESOM)

BESOM will be maintained and updated to reflect latest information and research and development progress. The input format of BESOM and the dynamic model will be refined so that assumptions will be more apparent to the user. Equations will be written so as to facilitate sensitivity analysis and provide additional useful information. In particular, defining variables representing installed capacity will aid the investigation of capital cost effects.

Task 2.2 Coordination of National Energy Models

A number of energy models developed elsewhere which may be applicable to Energy Research and Development Administration needs will be surveyed. Standards for design, documentation, and data format of models developed elsewhere will be prepared. Format and data specifications will be prepared for BESOM for distribution to other modeling groups who may be interested in relating their models to the ERDA analysis activity. Possibilities of running other models at Brookhaven will be evaluated in light of ERDA requirements and BNL software capabilities. Opportunities for coupling or combining models in order to enhance their analytical capability will be identified and investigated. Particular attention will be devoted to resource models under development at DRI and MIT.

Task 2.3 Support

An analysis of the effects of varying assumptions about electric generating capacity utilization factors will be performed. Studies will be made using supply and demand elasticities and with the cost of utilizing devices included in the optimization. Technical assistance will also be provided to Planning and Analysis on special topics to be identified.

Task 2.4 Regional Energy Model

Work will be initiated on the development of a nine region version of BESOM. The structure and software will be developed and a demonstration run will be made using national average efficiency and environmental data for each region and demands taken from the regional Reference Energy Systems.

Task 2.5 Time Stepped Version of BESOM

Work will be initiated on a time stepped version of BESOM to provide an improved simulation capability. Dynamic features of other energy models will be surveyed and evaluated for use in this task.

AREA 3 - TECHNOLOGY ASSESSMENT:

Task 3.1 Interfuel Substitution Studies

Reports will be issued on the coal and conservation studies during the transition period.

A study of the role of renewable resources will commence. Emphasis will be placed upon the techniques available or anticipated from solar (wind, ocean thermal, etc.) and geothermal (dry steam, hot rock, etc.) energy. Their potential impacts upon the energy system will be evaluated. Regional limitations will be considered, and economic and environmental effects will be estimated. The study will be completed in FY 1977, and a topical report will be issued.

Task 3.2 Technology Studies

a) Cognizance will be maintained of the R&D schedule and of implementation goals for new technologies to be used in on-going and future assessments. Specific attention will be given to the definition of technical and economic objectives to achieve the implementation goals. The assessment of energy technologies will be made a continuing effort for use in various areas of energy policy, and particularly in the area of R&D funding. Treatment of uncertainty is required to determine break-through levels for new technologies compared to their more conventional competitors and probabilistic approaches will be reviewed. BNL will assist ERDA in preparing the characterization of technologies in support of forecasts and normative planning.

b) The Reference Energy Systems developed for the Source-book for Energy Assessment will be updated to incorporate new trends in both energy use and technologies.

c) Maintenance of the cost base used in modeling work by the Technology Assessment Group and other groups is required. Costs will be updated to 1976 dollars, and capital costs will be converted to a format compatible with the Reference Energy System. End use device costs for use in energy demand sectors analysis will be updated for use both in the Reference Energy Systems and other models.

d) The multi-objective analysis technique has been applied in a preliminary fashion; however, some continued development is required. For future anticipated benefit/cost studies and technology assessments, it should be possible to include weighting functions for some of the parameters, and to add additional environmental factors to those presently employed to upgrade the environmental index that is used as a parameter.

Task 3.3 Introduction Rates of New Technologies

The study of introduction rates of new technologies will continue, and a topical report covering the results to date will be issued.

Task 3.4 Trans-National Comparisons

A study comparing energy use in the U.S. and Japan will be completed, and a similar study of Great Britain will be started.

Task 3.5 Special Studies and Assistance

The interdisciplinary effort employed previously will continue for all special tasks requested by ERDA.

Task 3.6 Decentralized Energy Systems

A study will be initiated of the role of decentralized energy systems in meeting future energy demands. Implementation levels will be estimated for fuel cells, wind power, solar heating, and cooling systems. The role of alternative energy carriers (gas, liquid, solid) will be evaluated. A preliminary Reference Energy System will be prepared and first order impacts on capital, resources, and emissions will be calculated. Work will be initiated on the definition of economic parameters to be used in judging overall impacts on the economy.

AREA 4 - ECONOMIC ANALYSIS

Task 4.1 Model Development

Extension of Static Input-Output Model

The I-O model will be extended so as to incorporate alternative vectors of current and capital input-output coefficients for one or more selected energy-intensive sectors. For example, for an intensive energy using sector (e.g., iron and steel) the previously estimated single vector of energy, materials, capital,

and labor coefficients will be disaggregated into several vectors, each of which is associated with a different type of industrial process (e.g., blast, open hearth, electric and basic oxygen furnaces for the iron and steel sector). The I-O model will then be extended so as to permit choice between different mixes of industrial processes, first on an ad hoc parameterization basis, then on a formal cost-minimizing criterion basis. This model extension will permit among other things, estimation of the economic effects of alternative energy end use processes within an industry.

Coupling of BNL and DRI Models

In conjunction with DRI, the price as well as the output structures of the BNL I-O and LP models will be aligned with those of the DRI interindustry and growth models and then, if feasible, the price structures of all the models will be formally linked and the magnitude of some of these linking relationships will be estimated. While this pricing aspect of the model coupling is being developed, the previously developed output-only coupling will be maintained for use in policy application.

Model Specifications

Format and data specifications will be prepared for the I-O model for distribution to other modeling groups who may be interested in relating their models to the ERDA analysis activity.

Task 4.2 Data Estimation

Estimation of Marginal I-O Process Coefficients

Drawing on the past work of Robert Ayres at IRT, work will begin on the estimation of future input coefficients for energy intensive utilizing industries for eventual insertion in the extended I-O model (see Task 4.1).

Task 4.3 Applications

Development of Energy Projections

Using both the I-O and LP models, three alternative sets of energy projections will be estimated for the 1985-2000 period, where each forecast will correspond to a different degree of energy conservation relative to the level of economic activity. The general specifications of each scenario will be provided by Planning and Analysis. The 1985-2000 aggressive conservation projections will be linked to the Federal Energy Administration (FEA) Conservation Case for 1975-1985, while the other projection will be linked to the FEA Business as Usual Case for 1975-1985. DRI will provide the macroeconomic projection for these forecasts.

Economic Analysis of Third ERDA RD&D Plan

In consultation with Planning and Analysis, the BNL and DRI policy analysts, models, and data base will be applied to estimate the economic impacts of the Third ERDA RD&D Plan. First the basic DRI economic forecast will be calibrated with the three sets of energy projections described above. These three sets of energy and economic projections will then be used as references against which the effects of several potential future economic and energy events will be measured. The general specifications of alternative future scenarios, along with the determination of target policy variables, such as the amount of oil and gas imports, will be provided by Planning and Analysis. The determination of the detailed model linkage structures to be used in analyzing each alternative will be provided jointly by BNL and DRI.

In this analysis, at least the following variables will be parameterized upon: the level and structure of the future GNP; the future availability and success rates of new energy technologies, and the level of taxes and tariffs which will be

imposed upon oil and gas imports and/or upon domestic oil and gas rates. The analysis of these model runs will be provided jointly by BNL and DRI to Planning and Analysis.

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TABLE 1. Sectoral Classification of Energy Input-Output Model
and Alignment with Other Classification Systems

BNL 110	Sector	BNL 101	BEA	Battelle	A.Carter	BLS
1	Coal	1	7	7	7	8
2	Crude oil & gas	2	8	8	8	9
3	Shale oil	-	-	-	-	-
4	Methane from coal	3	-	-	-	-
5	Solvent refined coal	-	-	-	-	-
6	Refined oil products	4	31.01	part 31	part 41	part 42
7	Pipeline gas	5	6E.02	68.2	93	102
8	Coal combined cycle electric	-	-	-	-	-
9	Other fossil electric	6	5E.01	-	-	-
10	LWR electric	7	6E.01	-	-	-
11	HTGR electric	-	-	68.1	92	101
12	Hydroelectric	8	6E.01	-	-	-
13	Orn reduction feedstocks	9	-	-	-	-
14	Chemical feedstocks	10	-	-	-	-
15	Motive power	11	-	-	-	-
16	Process heat	12	-	-	-	-
17	Water heat	13	-	-	-	-
18	Space heat	14	-	-	-	-
19	Air conditioning	15	-	-	-	-
20	Electric power	16	-	-	-	-
21	Livestock and livestock products	17	1	1	1	1
22	Other agricultural products	18	2	2	2	2
23	Forestry and fishery products	19	3	3	3	3
24	Agricultural, forestry and fishery services	20	4	4	4	4
25	Iron and ferroalloy ores mining	21	5	5	5	5
26	Nonferrous metal ores mining	22	6	6	6	5-7
27	Stone and clay mining and quarrying	23	9	9	9	10
28	Chemicals and fertilizer mineral mining	24	10	10	10	11
29	New construction, residential buildings	-	11.01	11.1	11	12
30	New construction, nonresidential buildings	-	11.02	11.2	12	13
31	New construction, public utilities	25	11.03	11.3	13	14
32	New construction, highways	-	11.04	11.4	14	15
33	New construction, all other	-	11.05	11.5	15	16
34	Maintenance and repair construction, residential	26	12.01	12.1	16	17
35	Maintenance and repair construction, all other	-	12.02	12.2	17	-
36	Ordinance and accessories	27	13	13	18	18-19
37	Food and kindred products	28	14	14	19	20
38	Tobacco manufactures	29	15	15	20	21
39	Broad and narrow fabrics, yarn and thread mills	30	16	16	21	22
40	Misc. textile goods and floor coverings	31	17	17	22	23
41	Apparel	32	18	18	23	24-25
42	Misc. fabricated textile products	33	19	19	24	26
43	Lumber and wood products, except containers	34	20	20	25	27, part 28
44	Wooden containers	35	21	21	26	part 28
45	Household furniture	36	22	22	27	29
46	Other furniture and fixtures	37	23	23	28	30
47	Paper and allied products except containers and boxes	38	24	24.1 24.2 24.3	29 30 31	31
48	Paperboard containers and boxes	39	25	25	32	32
49	Printing and publishing	40	26	26	33	33-34
50	Chemicals and selected chemical products	41	27	27.1 27.2 27.3	34 35 36	35-36
51	Plastics and synthetic materials	42	28	28.1 28.2	37 38	37
52	Drugs, cleaning and toilet preparations	43	29	29	39	39-40
53	Paints and allied products	44	30	30	40	41
54	Paving mixtures and blocks	45	30.02	part 31	part 41	part 42
55	Asphalt felts and coatings	46	31.03	part 31	part 41	part 42
56	Rubber and miscellaneous plastics products	47	32	32.1 32.2 32.3	42 43 44	43-44
57	Leather tanning and industrial leather products	48	33	33	45	45
58	Footwear and other leather products	49	34	34	46	-
59	Glass and glass products	50	35	35	47	46
60	Stone and clay products	51	36	36	48	47-48

BNL 110	Sector	BNL 101	BEA	Battelle	A.Carter	BLS
61	Primary iron and steel manufacturing	52	37	37	49	49-50
62	Primary nonferrous metals manufacturing	53	38	38.1 38.2 38.3	50 51 52	51-57
63	Metal containers	54	39	39	53	58
64	Heating, plumbing and fabricated structural metal products	55	40	40	54	59-60
65	Screw machine parts, bolts, nuts, etc. & metal stampings	56	41	41	55	61
66	Other fabricated metal products	57	42	42	56	62
67	Engines and turbines	58	43	43	57	63
68	Farm machinery	59	44	44	58	64
69	Construction, mining, oil field machinery, equipment	60	45	45	59	65
70	Materials handling machinery and equipment	61	46	46	60	66
71	Metalworking machinery and equipment	62	47	47	61	67
72	Special industry machinery and equipment	63	48	48	62	68
73	General industrial machinery and equipment	64	49	49	63	69
74	Machine shop products	65	50	50	64	70
75	Office, computing and accounting machines	66	51	51	65	71-72
76	Service industry machines	67	52	52	66	73
77	Elec. trans. & dist. eq. & elec. industry apparatus	68	53	53.1 53.2	67 68	74 75
78	Household appliances	69	54	54	69	76
79	Electric lighting and wiring equipment	70	55	55	70	77
80	Radio, television and communications equipment	71	56	56	71	78-80
81	Electronic components and accessories	72	57	57.1 57.2 57.3	72 73 74	81
82	Miscellaneous elec. machinery, equipment & supplies	73	58	58	75	82
83	Motor vehicles and equipment	74	59	59	76	83
84	Aircraft and parts	75	60	60	77	84
85	Other transportation equipment	76	61	61	78	85-87
86	Professional, scientific & controlling inst. & supp.	77	62	62	79	88-89
87	Optical, ophthalmic, & photographic equip. & supp.	78	63	63	81	90-91
88	Miscellaneous manufacturing	79	64	64	82	92
89	Railroads and related services	80	65.01	65.1	83	93
90	Local, suburban & interurban highway pass. trans.	81	65.02	65.2	84	94
91	Motor freight transportation and warehousing	82	65.03	65.3	85	95
92	Water transportation	83	65.04	65.4	86	96
93	Air transportation	84	65.05	65.5	87	97
94	Pipe line transportation	85	65.06	65.6	88	98
95	Transportation services	86	65.07	65.7	89	-
96	Communications except radio & television broadcasting	87	66	66	90	99
97	Radio and TV broadcasting	88	67	67	91	100
98	Water and sanitary services	89	68.03	68.3	94	103
99	Wholesale and retail trade	90	69	69	95	104-105
100	Finance and insurance	91	70	70	96	106-107
101	Real estate & rental	92	71	71	97	108-109
102	Hotels & lodging; pers. & repair serv., except auto repair	93	72	72	98	110-111
103	Business services	94	73	73	99	112-114
104	Automobile repair & services	95	75	75	101	115
105	Amusements	96	76	76	102	116-117
106	Medical, educ. services & nonprofit inst.	97	77	77	103	118-121
107	Federal government enterprises	98	78	-	104	122-124
108	State and local government enterprises	99	79	-	105	125
109	Business travel, entertainment & gifts	100	81	-	107	128
110	Office supplies	101	82	-	108	129
-	Research & development	-	74	-	100	-
-	Gross imports	-	80	-	106	126-127
-	Scrap, used and second hand goods	-	83	-	109	-
-	Government industry	-	84	-	-	131
-	Rest of world industry	-	85	-	-	132
-	Households	-	86	-	-	133
-	Inventory valuation adjustment	-	87	-	-	134

*Eliminated as a separate sector by BEA in the 1963 and 1967 studies.

Code BNL 110 - 110 sector version

BNL 101 - 101 sector version

BEA - Bureau of Economic Analysis, U.S. Dept. of Commerce

Battelle- Classification used in reference (7).

A.Carter- Professor Ann Carter, Brandeis University

BLS - Bureau of Labor Statistics, U.S. Dept. of Labor

TABLE 2

Correspondence Between I-O and LP Energy Supply Categories

<u>I-O Model Supply Sectors</u>	<u>LP Supply Categories*</u>
1. Coal	Coal, Underground Coal, Stripmined
2. Crude Oil & Gas	Oil, Domestic Oil, Imported Natural Gas
3. Shale Oil	Oil, Shale
4. Methane from Coal	Methane from Coal
5. Coal Liquefaction	Coal Liquefaction
6. Refined Oil Products	-----
7. Pipeline Gas	-----
8. Coal Combined-Cycle Electric	Coal Fired Steam Electric, Combined Cycle
9. Other Fossil Electric	Coal Fired Steam Electric Oil Fired Steam Electric Oil Fired Steam Electric, Combined Cycle Oil Fired Gas Turbine Gas Fired Steam Electric Total Energy Systems
10. LWR Electric	Light Water Reactor
11. HTGR Electric	High Temperature Gas-Cooled Reactor
12. Hydroelectric	Hydroelectric Geothermal Solar Direct Thermal Pumped Storage Solar Electric

*The following LP supply categories are not used in the combined I-O/LP model: Liquid Metal Fast Breeder Reactor, Synthetic Natural Gas from Oil, Hydrogen from Electrolysis, Methanol from Coal, and Hydrogen from Coal

TABLE 3

Correspondence Between I-O and
LP Energy Product Categories

<u>I-O Model</u> <u>Product Sectors</u>	<u>LP Demand Categories</u>
Ore Reduction Feedstocks (Coke)	Iron
Chemical Feedstocks	Petrochemicals
Motive Power	Air Transport
	Truck, Bus, Non-Electric Rail
	Automobile
Process Heat	Miscellaneous Thermal
Water Heat	Water Heat
Space Heat	Space Heat
Air Conditioning	Air Conditioning
Electric Power	Miscellaneous Electric (Base, Intermediate, and Peak Load)
	Electric Rail

TABLE 4. Feasible LP Solution Variables for Energy Input-Output Model

SUPPLY CATEGORIES	DEMAND CATEGORIES																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
COAL FIRED STEAM ELECTRIC	1																					
COAL FIRED STEAM ELECTRIC COMBINED CYCLED	2																					
OIL FIRED STEAM ELECTRIC	3																					
OIL FIRED STEAM ELECTRIC COMBINED CYCLED	4																					
OIL FIRED GAS TURBINE	5																					
GAS FIRED STEAM ELECTRIC	6																					
TOTAL ENERGY SYSTEMS	7																					
LIGHT WATER REACTOR	8																					
	9																					
HIGH TEMPERATURE GAS-COOLED REACTOR	10																					
HYDROELECTRIC	11																					
GEOTHERMAL	12																					
SOLAR ELECT&THERMAL	13																					
PUMPED STORAGE	14																					
	15																					
OIL, DOMESTIC	16																					
OIL, IMPORTED	17																					
OIL, SHALE	18																					
NATURAL GAS	19																					
	20																					
METHANE FROM COAL	21																					
COAL, UNDERGROUND	22																					
COAL, STRIPMINED	23																					
	24																					
	25																					
	26																					
COAL LIQUEFACTION	27																					

595 DOMESTIC OIL
596 IMPORTED OIL
597 UNDERGROUND COAL
598 STRIPMINED COAL
601 NATURAL GAS
602 SHALE OIL

NOTE: SHADED ACTIVITIES
DENOTE FEASIBLE
SOLUTION VARIABLES

TABLE 5

Unit Measure Definitions for I-O Energy Supplies
and Accounting System for Losses

RC - Raw, extracted coal	PG - Processed pipeline quality gas
CCL - Coal cleaning loss	GTL - Gas transmission loss
CC - Cleaned coal	DG - Delivered gas
SO - Crude synthetic oil from coal	CSO - Crude shale oil
COG - Crude oil and gas	SRL - Shale oil refining loss
CO - Crude oil	GE - Generated electricity
CRL - Crude refining loss	ETL - Electric trans/dist loss
ROP - Refined oil products	DE - Delivered electricity

- 1) raw coal - coal cleaning loss = cleaned coal

$$RC - CCL = CC$$

- 2) crude oil and gas - oil refining loss - gas
processing loss = refined oil products + processed,
pipeline-quality gas

$$COG - CRL = ROP + PG$$

- 3) crude shale oil - shale oil refining loss =
refined oil products

$$CSO - SRL = ROP$$

- 4) processed, pipeline-quality gas - dist/trans
loss = delivered gas

$$PG - GTL = DG$$

- 5) generated electricity - dist/trans loss = delivered electricity

$$GE - ETL = DE$$

TABLE 6

Unit Measures for I-O Coefficients Calculated from LP Solution, Final Demands, and Total Outputs

	1. Coal	2. Crude Oil & Gas	3. Shale Oil	4. Methane from Coal	5. Synthetic Oil from Coal	6. Refined Oil Products	7. Pipeline Gas	8. Coal Comb/Cycle Electric	9. Other Fossil Electric	10. LWR Electric	11. HTGR Electric	12. Hydroelectric & Other	13. Ore Reduction Feedstocks, ORF	14. Chemical Feedstocks, CF	15. Motive Power, MP	16. Process Heat, PH	17. Water Heat, WH	18. Space Heat, SH	19. Air Conditioning, AC	20. Electric Power, EP	Final Demand (Exports, Inventory Change, Imports)	Total Output
1.				RC PG	RC SO			RC GE	RC GE				RC ORE	RC CF		RC PH					RC	RC
2.	CRL					ROP	PG														CO	COG
3.		COG				ROP	PG															CSO
4.			SRL			ROP																PG
5.			CSO			ROP																SO
6.					SO		PG															ROP
7.					ROP		PG															PG
8.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
9.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
10.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
11.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
12.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
13.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
14.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
15.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
16.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
17.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
18.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
19.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
20.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
21.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
22.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
23.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
24.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
25.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
26.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
27.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
28.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
29.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
30.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
31.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
32.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
33.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
34.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
35.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
36.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
37.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
38.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
39.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
40.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
41.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
42.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
43.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
44.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
45.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
46.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
47.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
48.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
49.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
50.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
51.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
52.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
53.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
54.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
55.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
56.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
57.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
58.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
59.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
60.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
61.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
62.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
63.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
64.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
65.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
66.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
67.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
68.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
69.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
70.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
71.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
72.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
73.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
74.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
75.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
76.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
77.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
78.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
79.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
80.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
81.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
82.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
83.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
84.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
85.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
86.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
87.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
88.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
89.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
90.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
91.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
92.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
93.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
94.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
95.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
96.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
97.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
98.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
99.								ROP	GE					ROP	ROP	ROP	ROP	ROP				
100.								ROP	GE					ROP	ROP	ROP	ROP	ROP				

I/O Coefficients $a_{ij} = T_{ij}/X_j$, where T_{ij}/X_j are measured in units shown above.

Note: Abbreviations are defined in Table V and at top of Figure.

* Losses are for hydro and geothermal, but not for pumped storage and solar.

TABLE 7

Comparison of Results for Multi-Objective Analysis

	<u>"BEST" CASE</u>		<u>MINIMUM COST CASE</u>	
	<u>1985</u>	<u>2000</u>	<u>1985</u>	<u>2000</u>
TOTAL COST, 10^9 Dollars	185.0	301.2	179.7	295.7
IMPORTED OIL, 10^{15} Btu	15.9	0.0	14.7	0.0
ENVIRONMENTAL INDEX, Weighted Units	625.0	600.0	692.6	691.3
RESOURCE USE, 10^{15} Btu	92.2	126.5	93.2	125.4
CAPITAL, 10^9 Dollars	538.3	1277.0	595.4	1342.7
TOTAL OIL, 10^{15} Btu	40.0	17.0	38.8	19.7

TABLE 8

General Specification of Policies A1 and A2

<u>"Tariff plus RD&D" Policy A1:</u>	<u>1985</u>	<u>1990</u>	<u>2000</u>
Crude oil tariff and tax (%) ^a	51.8	62.2	166.0
Crude gas tariff and tax (%) ^a	0.0	11.9	21.6
Additional energy supplies due to RD&D (quads) ^b	4.90	9.70	22.00
 <u>"Tariff only" Policy A2:</u>			
Crude oil and gas tariff and tax (%) ^{a, c}	48	125	230

^a Percent of Base Case crude price.

^b Quadrillion Btu's of primary energy input; increment of the Base Case including oil shale, coal liquefaction, coal gasification, direct solar, LWR, HTGR, geothermal, solar electric and total energy systems.

^c In Policy A2, tariffs on oil and gas are assumed to be the same.

TABLE 9

Amounts of Oil and Gas Import Reductions Achieved by
Policy A1 by Source of Reduction
(Figures in quadrillion Btu)

	<u>1985</u>	<u>1990</u>	<u>2000</u>
A. Reduction of Oil and Gas Imports from Base Case Amounts	8.42	16.22	40.10
B. Amount of Reduction by Source			
I. <u>Reduced Demand for Energy via</u> <u>Price Increases</u>	3.30	6.90	20.31
II. <u>Increased New Primary Supplies</u>			
Oil Shale	1.00	1.80	7.95
Direct Solar	0.20	0.97	4.50
Solar Electric	0.00	0.00	1.32
Geothermal Electric	<u>0.97</u>	<u>1.79</u>	<u>4.20</u>
TOTAL	2.17	4.56	17.97
III. <u>Additional Use of Coal or Uranium</u>			
Coal Gasification and			
Liquefaction	1.42	3.26	4.00
LWR Electric	0.96	1.49	0.00
HTGR Electric	<u>0.25</u>	<u>0.37</u>	<u>0.00</u>
TOTAL	2.63	5.12	4.00
IV. <u>Electric Car</u>	.09	.30	1.86
V. <u>Other</u>	<u>.23</u>	<u>-.66</u>	<u>-4.04</u>
GRAND TOTAL	8.42	16.22	40.10

TABLE 10

Energy and Economic Effects of Policy A1

	<u>1985</u>	<u>1990</u>	<u>2000</u>
Energy input: ^a			
Base Case (quads)	100.00	115.3	156.2
Policy A1 (quads)	96.80	108.42	135.91
Change (%)	-3.20	-5.97	-12.99
Effects: Percentage change from Base Case in			
GNP ^b (%)	0.132	0.164	0.420
Real GNP ^b (%)	-1.125	-1.614	-2.853
Real growth ^c (%/yr)	-	-0.103	-0.132
Price level ^d (%)	1.27	1.81	3.37
Inflation ^e (%/yr)	-	.112	.157
Capital quantity (%)	-1.00	-1.73	-2.49
Labor quantity ^h (%)	- .37	-0.44	-0.59
Energy: Real GNP ratio ^f			
Base Case	50.31	48.02	43.54
Policy A1	49.26	45.90	39.00
Change (%)	-2.09	-4.41	-10.43
Energy saving due to			
Lower Real GNP (quads)	1.13	1.86	4.46
More efficient use ^g (quads)	2.08	5.02	15.83
Unemployment Rate: Policy A1 (%)	5.17	5.24	5.39

^aEnergy input is primary energy input, quadrillion Btu's.

^bGross national product includes the imputed value of services of household capital.

^cReal growth change is the difference, in percentage points per annum, in the rate of growth of real GNP over the intervals 1980-85, 1985-90, and 1990-2000.

^dThe price level is the GNP price deflator.

^eThe change in inflation is the difference, in percentage points per annum, in the inflation rate over the periods 1980-85, 1985-90 and 1990-2000 respectively.

^fEnergy: GNP ratio is trillion Btu per billion 1971 dollars, 10^{12} Btu/ 10^9 \$71.

^gMore efficient use of energy is energy saved by reduction in the energy:real GNP ratio. Energy is in quadrillion Btu's.

^hThis equals the percentage increase in the unemployment rate.

TABLE 11

Energy and Economic Effects of Policy A2

	<u>1985</u>	<u>1990</u>	<u>2000</u>
Energy input: ^a			
Base Case (quads)	100.0	115.3	156.2
Policy A2 (quads)	93.5	97.8	117.9
Change (%)	-6.5	-15.1	-24.4
Effects: Percentage change from Base Case in: ^b			
GNP ^b (%)	0.16	0.39	0.55
Real GNP ^b (%)	-1.27	-2.70	-4.71
Real growth ^c (%/yr)	-0.26	-0.29	-0.20
Price level ^d (%)	1.44	3.17	5.52
Inflation ^c (%/yr)	0.29	0.34	0.23
Capital quantity (%)	-0.39	-0.85	-1.23
Labor quantity (%)	-0.45	-0.69	-0.51
Energy: Real GNP ratio ^f			
Base Case	50.30	47.87	43.34
Policy A2	47.64	41.76	34.38
Change (%)	-5.29	-12.76	-20.87
Energy saving due to:			
Lower Real GNP (quads)	1.3	3.1	7.4
More efficient use ^g (quads)	5.2	14.3	30.8
Unemployment rate: Policy A2 (%)	5.25	5.49	5.31

^a Energy input is primary energy input, quadrillion Btu's.

^b Gross national product includes the imputed value of services of household capital.

^c Real growth change is the difference, in percentage points per annum, in the rate of growth of real GNP over the intervals 1980-85, 1985-90, and 1990-2000.

^d The price level is the GNP price deflator.

^e The change in inflation is the difference, in percentage points per annum, in the inflation rate over the periods 1980-85, 1985-90, and 1990-2000 respectively.

^f Energy: GNP ratio is trillion Btu per billion 1971 dollars, 10^{12} Btu/ 10^9 \$71.

^g More efficient use of energy is energy saved by reduction in the energy: real GNP ratio. Energy is in quadrillion Btu's.

TABLE 12
EMOB - SUPPLY PROCESS LIST
02/18/76

ID	RESOURCE	ACTIVITY	PROCESS	REGION	CONTROL
---	-----	-----	-----	-----	-----
1	COAL	CONVERSION	BEE HIVES	NATIONAL	CONTROLLED
2	COAL	CONVERSION	BEE HIVES	NATIONAL	UNCONTROLLED
3	COAL	CONVERSION	SLOT OVENS	NATIONAL	CONTROLLED
4	COAL	CONVERSION	SLOT OVENS	NATIONAL	UNCONTROLLED
13	COAL	DISTRIBUTION	CONVEYOR	CENTRAL APPALACHIA	CONTROLLED
14	COAL	DISTRIBUTION	CONVEYOR	CENTRAL APPALACHIA	UNCONTROLLED
15	COAL	DISTRIBUTION	CONVEYOR	CENTRAL REGION	CONTROLLED
16	COAL	DISTRIBUTION	CONVEYOR	CENTRAL REGION	UNCONTROLLED
19	COAL	DISTRIBUTION	CONVEYOR	NATIONAL	CONTROLLED
20	COAL	DISTRIBUTION	CONVEYOR	NATIONAL	UNCONTROLLED
17	COAL	DISTRIBUTION	CONVEYOR	NORTHERN APPALACHIA	CONTROLLED
18	COAL	DISTRIBUTION	CONVEYOR	NORTHERN APPALACHIA	UNCONTROLLED
21	COAL	DISTRIBUTION	MIXED TRAIN	CENTRAL APPALACHIA	CONTROLLED
22	COAL	DISTRIBUTION	MIXED TRAIN	CENTRAL APPALACHIA	UNCONTROLLED
23	COAL	DISTRIBUTION	MIXED TRAIN	CENTRAL REGION	CONTROLLED
24	COAL	DISTRIBUTION	MIXED TRAIN	CENTRAL REGION	UNCONTROLLED
27	COAL	DISTRIBUTION	MIXED TRAIN	NATIONAL	CONTROLLED
28	COAL	DISTRIBUTION	MIXED TRAIN	NATIONAL	UNCONTROLLED
25	COAL	DISTRIBUTION	MIXED TRAIN	NORTHERN APPALACHIA	CONTROLLED
26	COAL	DISTRIBUTION	MIXED TRAIN	NORTHERN APPALACHIA	UNCONTROLLED
29	COAL	DISTRIBUTION	MIXED TRAIN	NORTHWEST REGION	CONTROLLED
30	COAL	DISTRIBUTION	MIXED TRAIN	NORTHWEST REGION	UNCONTROLLED
31	COAL	DISTRIBUTION	PIPELINE	NATIONAL	CONTROLLED
32	COAL	DISTRIBUTION	PIPELINE	NATIONAL	UNCONTROLLED
5	COAL	DISTRIBUTION	RIVER BARGE	CENTRAL APPALACHIA	CONTROLLED
6	COAL	DISTRIBUTION	RIVER BARGE	CENTRAL APPALACHIA	UNCONTROLLED
7	COAL	DISTRIBUTION	RIVER BARGE	CENTRAL REGION	CONTROLLED
8	COAL	DISTRIBUTION	RIVER BARGE	CENTRAL REGION	UNCONTROLLED
11	COAL	DISTRIBUTION	RIVER BARGE	NATIONAL	CONTROLLED
12	COAL	DISTRIBUTION	RIVER BARGE	NATIONAL	UNCONTROLLED
9	COAL	DISTRIBUTION	RIVER BARGE	NORTHERN APPALACHIA	CONTROLLED
10	COAL	DISTRIBUTION	RIVER BARGE	NORTHERN APPALACHIA	UNCONTROLLED
33	COAL	DISTRIBUTION	TRUCKING	CENTRAL APPALACHIA	CONTROLLED
34	COAL	DISTRIBUTION	TRUCKING	CENTRAL APPALACHIA	UNCONTROLLED
35	COAL	DISTRIBUTION	TRUCKING	CENTRAL REGION	CONTROLLED
36	COAL	DISTRIBUTION	TRUCKING	CENTRAL REGION	UNCONTROLLED
39	COAL	DISTRIBUTION	TRUCKING	NATIONAL	CONTROLLED
40	COAL	DISTRIBUTION	TRUCKING	NATIONAL	UNCONTROLLED
37	COAL	DISTRIBUTION	TRUCKING	NORTHERN APPALACHIA	CONTROLLED
38	COAL	DISTRIBUTION	TRUCKING	NORTHERN APPALACHIA	UNCONTROLLED
41	COAL	DISTRIBUTION	TRUCKING	NORTHWEST REGION	CONTROLLED
42	COAL	DISTRIBUTION	TRUCKING	NORTHWEST REGION	UNCONTROLLED
43	COAL	DISTRIBUTION	UNIT TRAIN	CENTRAL APPALACHIA	CONTROLLED
44	COAL	DISTRIBUTION	UNIT TRAIN	CENTRAL APPALACHIA	UNCONTROLLED
45	COAL	DISTRIBUTION	UNIT TRAIN	CENTRAL REGION	CONTROLLED
46	COAL	DISTRIBUTION	UNIT TRAIN	CENTRAL REGION	UNCONTROLLED
49	COAL	DISTRIBUTION	UNIT TRAIN	NATIONAL	CONTROLLED
50	COAL	DISTRIBUTION	UNIT TRAIN	NATIONAL	UNCONTROLLED
47	COAL	DISTRIBUTION	UNIT TRAIN	NORTHERN APPALACHIA	CONTROLLED
48	COAL	DISTRIBUTION	UNIT TRAIN	NORTHERN APPALACHIA	UNCONTROLLED
51	COAL	DISTRIBUTION	UNIT TRAIN	NORTHWEST REGION	CONTROLLED

TABLE 13
EMDE - UTILIZ PROCESS LIST
02/18/76

ID	SECTOR	ACTIVITY	PROCESS	FUEL	CONTROL
1	COMMERCIAL	APPLIANCES	MISCELLANEOUS APPLIANCES	ELECTRICITY	UNCONTROLLED
2	COMMERCIAL	FEEDSTOCK	ROAD MATERIAL	ASPHALT	UNCONTROLLED
3	COMMERCIAL	KITCHEN	COOKING UNIT	ELECTRICITY	UNCONTROLLED
5	COMMERCIAL	KITCHEN	COOKING UNIT	LIQUID PROPANE GAS	UNCONTROLLED
4	COMMERCIAL	KITCHEN	COOKING UNIT	NATURAL GAS	UNCONTROLLED
6	COMMERCIAL	KITCHEN	STANDARD REFRIGERATOR-FREEZER	ELECTRICITY	UNCONTROLLED
7	COMMERCIAL	KITCHEN	WATER HEATER	ELECTRICITY	UNCONTROLLED
9	COMMERCIAL	KITCHEN	WATER HEATER	LIQUID PROPANE GAS	UNCONTROLLED
8	COMMERCIAL	KITCHEN	WATER HEATER	NATURAL GAS	UNCONTROLLED
10	COMMERCIAL	LIGHTING	INDOOR LIGHTS	ELECTRICITY	UNCONTROLLED
11	COMMERCIAL	LIGHTING	STREET LIGHTS	ELECTRICITY	UNCONTROLLED
12	COMMERCIAL	SPACE CONDITIONING	ELECTRIC AIR CONDITIONER	ELECTRICITY	UNCONTROLLED
13	COMMERCIAL	SPACE CONDITIONING	GAS AIR CONDITIONER	ELECTRICITY	UNCONTROLLED
14	COMMERCIAL	SPACE CONDITIONING	GAS AIR CONDITIONER	NATURAL GAS	UNCONTROLLED
15	COMMERCIAL	SPACE CONDITIONING	SPACE HEATER	COAL	UNCONTROLLED
16	COMMERCIAL	SPACE CONDITIONING	SPACE HEATER	DISTILLATE OIL	UNCONTROLLED
18	COMMERCIAL	SPACE CONDITIONING	SPACE HEATER	LIQUID PROPANE GAS	UNCONTROLLED
17	COMMERCIAL	SPACE CONDITIONING	SPACE HEATER	NATURAL GAS	UNCONTROLLED
19	COMMERCIAL	SPACE CONDITIONING	SPACE HEATER	RESIDUAL OIL	UNCONTROLLED
20	INDUSTRIAL	SIC20	BAKERY, SUGAR PRODUCTS	AGGREGATION OF FUELS	UNCONTROLLED
21	INDUSTRIAL	SIC20	BAKERY, SUGAR PRODUCTS	COAL	UNCONTROLLED
22	INDUSTRIAL	SIC20	BAKERY, SUGAR PRODUCTS	COKE	UNCONTROLLED
23	INDUSTRIAL	SIC20	BAKERY, SUGAR PRODUCTS	DISTILLATE OIL	UNCONTROLLED
24	INDUSTRIAL	SIC20	BAKERY, SUGAR PRODUCTS	ELECTRICITY	UNCONTROLLED
25	INDUSTRIAL	SIC20	BAKERY, SUGAR PRODUCTS	NATURAL GAS	UNCONTROLLED
26	INDUSTRIAL	SIC20	BAKERY, SUGAR PRODUCTS	RESIDUAL OIL	UNCONTROLLED
27	INDUSTRIAL	SIC20	BEVERAGE, CAN PRODUCTS	AGGREGATION OF FUELS	UNCONTROLLED
28	INDUSTRIAL	SIC20	BEVERAGE, CAN PRODUCTS	COAL	UNCONTROLLED
29	INDUSTRIAL	SIC20	BEVERAGE, CAN PRODUCTS	DISTILLATE OIL	UNCONTROLLED
30	INDUSTRIAL	SIC20	BEVERAGE, CAN PRODUCTS	ELECTRICITY	UNCONTROLLED
31	INDUSTRIAL	SIC20	BEVERAGE, CAN PRODUCTS	NATURAL GAS	UNCONTROLLED
32	INDUSTRIAL	SIC20	BEVERAGE, CAN PRODUCTS	RESIDUAL OIL	UNCONTROLLED
33	INDUSTRIAL	SIC20	GRAIN MILL & MISC FOOD	AGGREGATION OF FUELS	UNCONTROLLED
34	INDUSTRIAL	SIC20	GRAIN MILL & MISC FOOD	COAL	UNCONTROLLED
35	INDUSTRIAL	SIC20	GRAIN MILL & MISC FOOD	DISTILLATE OIL	UNCONTROLLED
36	INDUSTRIAL	SIC20	GRAIN MILL & MISC FOOD	ELECTRICITY	UNCONTROLLED
37	INDUSTRIAL	SIC20	GRAIN MILL & MISC FOOD	NATURAL GAS	UNCONTROLLED
38	INDUSTRIAL	SIC20	GRAIN MILL & MISC FOOD	RESIDUAL OIL	UNCONTROLLED
39	INDUSTRIAL	SIC20	MEAT, DAIRY PRODUCTS	AGGREGATION OF FUELS	UNCONTROLLED
40	INDUSTRIAL	SIC20	MEAT, DAIRY PRODUCTS	COAL	UNCONTROLLED
41	INDUSTRIAL	SIC20	MEAT, DAIRY PRODUCTS	DISTILLATE OIL	UNCONTROLLED
42	INDUSTRIAL	SIC20	MEAT, DAIRY PRODUCTS	ELECTRICITY	UNCONTROLLED
43	INDUSTRIAL	SIC20	MEAT, DAIRY PRODUCTS	NATURAL GAS	UNCONTROLLED
44	INDUSTRIAL	SIC20	MEAT, DAIRY PRODUCTS	RESIDUAL OIL	UNCONTROLLED
45	INDUSTRIAL	SIC26	PAPER PRODUCTS MANUFACTURE	AGGREGATION OF FUELS	UNCONTROLLED
46	INDUSTRIAL	SIC26	PAPER PRODUCTS MANUFACTURE	COAL	UNCONTROLLED
47	INDUSTRIAL	SIC26	PAPER PRODUCTS MANUFACTURE	DISTILLATE OIL	UNCONTROLLED
48	INDUSTRIAL	SIC26	PAPER PRODUCTS MANUFACTURE	ELECTRICITY	UNCONTROLLED
49	INDUSTRIAL	SIC26	PAPER PRODUCTS MANUFACTURE	NATURAL GAS	UNCONTROLLED
50	INDUSTRIAL	SIC26	PAPER PRODUCTS MANUFACTURE	RESIDUAL OIL	UNCONTROLLED
51	INDUSTRIAL	SIC26	PAPER, PULP MILLS	AGGREGATION OF FUELS	UNCONTROLLED
52	INDUSTRIAL	SIC26	PAPER, PULP MILLS	COAL	UNCONTROLLED

Figure 1. Reference energy system, year 1972.

Figure 2. Reference energy system, year 1980.

Figure 3. Reference energy system, year 1985.

Figure 4. Reference energy system, year 1990.

Figure 5. Reference energy system, year 2000.

Figure 6. Reference energy system, year 2020.

Figure 7. Comparison of energy growth projections.

Figure 8. Relation between DRI combined model and BNL combined model.

Figure 9. DRI combined growth and inter-industry energy model.

Figure 10. BNL combined input-output and energy linear programming allocation model.

Figure 11. Aggregate reference material system mass flow in million pounds (year 1972).

NOTE: NUMBERS IN PARENTHESES REFER TO FRACTION ELECTRICAL, AT A HEAT RATE OF 10,500 BTU PER KWH.

Figure 12. Aggregate reference material system energy requirement in 10^{12} Btu (year 1972).

Figure 13. 2000 system cost-environment tradeoff.

Figure 14. 2000 system cost-resource tradeoff.

Note: The EMDB supply and utilization files (SUPPLY, UTILIZ respectively) consist of many "logical entries" (i.e., processes). Each process consists of many data elements. Each data element is documented with a set of reference and footnotes.

Figure 15. Logical entry structure for the EMDB supply and utilization files.

Note: The EMDB documentation file consists of the text associated with reference or footnote numbers. Each reference or footnote entry consists of many lines of text, each with a unique line number.

Figure 16. Logical structure for the EMDB documentation file.

*PRINT PROCESS(40)

NO ERRORS HAVE OCCURRED
- SELECTED RG IS 60

06/04/76

COAL
DISTRIBUTION
TRUCKING
NATIONAL
UNCONTROLLED

MARKET ALLOCATION

1.260E-01

QUAL= 1

PRIMARY EFFICIENCY

1.000E+00

QUAL= 2

PRIMARY FUEL, PHYSICAL LOSS

N.A.

ANCILLARY FUEL, OIL

1.460E+10

QUAL= 3 DEC.09,1974

ANCILLARY FUEL, ELECTRICITY

0.

QUAL= 1 FEB.19,1975

ANCILLARY ENERGY, TOTAL

9.170E+08 BTU/10E12 BTU(IN)

QUAL= 4

PARTICULATES

1.640E+01 TONS/10E12 BTU(IN)

QUAL= 4 OCT.16,1974

OXIDES OF NITROGEN

1.220E+00 TONS/10E12 BTU(IN)

QUAL= 4

OXIDES OF SULFUR

8.910E-02 TONS/10E12 BTU(IN)

QUAL= 4

HYDROCARBONS

1.220E-01 TONS/10E12 BTU(IN)

QUAL= 4

CARBON MONOXIDE

7.430E-01 TONS/10E12 BTU(IN)

QUAL= 4

ALDEHYDES, ETC.

1.980E-02 TONS/10E12 BTU(IN)

QUAL= 4

TOTAL AIR POLLUTANTS

1.860E+01 TONS/10E12 BTU(IN)

QUAL= 4 OCT.16,1974

LAND USE

1.580E+00 ACRES/10E12 BTU(IN)

QUAL= 2

OCCUPATIONAL DEATHS

3.240E-02 NUMBER/10E12 BTU(IN)

QUAL= 3

OCCUPATIONAL INJURIES

6.920E-01 NUMBER/10E12 BTU(IN)

QUAL= 3

OCCUPATIONAL MAN DAYS LOST

4.540E+01 NUMBER/10E12 BTU(IN)

QUAL= 3

FIXED COST

1.850E+03 DOLLARS/10E12 BTU(IN)

QUAL= 3

OPERATING COST

1.670E+04 DOLLARS/10E12 BTU(IN)

QUAL= 3

TOTAL COST

1.850E+04 DOLLARS/10E12 BTU(IN)

QUAL= 2

Figure 17. A sample EMDB data retrieval
using S2K.