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THE
ENERGY MODEL DATA BASE
PROGRAM

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INTRODUCTION

The techniques of systems modeling and the methods of system analysis have proved to be very powerful aids in the attempts to understand how complex systems function and evolve. With these techniques and methods, sufficient simplification of the complexity can be obtained so that manipulation of the salient features will provide a reasonably realistic, but transparent, picture of system behavior under a wide range of conditions. In recent years, the network of technological processes and activities which provide the nation's energy requirements, starting with available resources and ending with consumer demands, has come in for detailed analysis. Many energy-related models have been constructed. Each of these has proceeded to simplify the complex energy system in such a way as to isolate selected system factors for subsequent manipulation.

The choice of which system features are of primary importance is usually dictated by the policy perspective of its potential user community. For example, the models developed by the National Center for Analysis of Energy Systems (NCAES) at Brookhaven were developed principally to provide a descriptive or normative overview of the technological aspects of the national energy system in order to permit analysis and intercomparison of the impact of future technological options. The quality of such models is usually determined by the success of the modeler in preserving a realistic picture of the system under the simplifying assumptions adopted and in maintaining relevance to policy objectives. Since the mathematical methods for model manipulation are generally rigorous, the quality of the results of such manipulations is largely determined by the quality of the numeric data used to parameterize the various characteristics

of the system being modeled.

To meet the needs of the NCAES for high quality numeric data, a flexible, open-ended and model-independent computerized data system has been developed and named the Energy Model Data Base (EMDB). It has been designed to accept files of numeric quantities useful in energy systems modeling, together with the documentation which indicates the source and quality of the numbers. As noted, the EMDB is independent of any particular model, but choices made in both content and format reflect the requirements of the NCAES modeling programs. The purpose of this paper is to provide a non-technical description of the content of the EMDB and to indicate its linkage to Brookhaven optimization and network flow models.

EMDB CONTENT

The clarity of the following description will be enhanced if some terms are defined at the beginning. The terminology adopted can best be understood in relation to a hierarchy of levels of aggregation at which the flow of energy through the energy system are considered. Five levels are used, and these are defined, primarily by examples, as follows:

Element - a single quantity, such as sulphur oxide emissions, land use, or operating cost associated with a process.

Process - a single technological operation, such as coal transportation by unit train, electric power generation by a light-water reactor, or steel production by electric furnace.

Activity - a system component, such as coal transportation, electricity generation, or steel production.

Trajectory - a linked series of processes, such as offshore oil extraction to freight transportation by diesel truck.

Sub-System - a related collection of trajectories, such as coal extraction to all coal uses.

As an example, the set of trajectories which constitute the current coal sub-system are shown for illustrative purposes in Figure 1, with the activities identified across the top of the figure and the processes noted on the trajectory links. The end-use processes are not detailed but are indicated symbolically.

The EMDb presently contains approximately 635 supply processes for current technologies and approximately 180 supply processes for future technologies, associated with different fuels, activities, regions, and control technologies. On the utilization side, it presently contains approximately 220 processes for fuel-specific end-use demands. The set of end-use processes (without the fuels utilized for each) are shown by sector in Figure 2 (residential),

COAL SUPPLY SUBSYSTEM

Figure 1

Figure 2

EMDB RESIDENTIAL ENERGY DEMANDS

ACTIVITY	PROCESS
• SPACE CONDITIONING	SPACE HEATER CENTRAL AIR CONDITIONER ROOM AIR CONDITIONER
• WATER HEATING	WATER HEATER AUTOMATIC CLOTHES WASHER MANUAL CLOTHES WASHER CLOTHES DRYER WATER PUMP
• KITCHEN	STANDARD OVEN-RANGE AUTOMATIC-CLEAN OVEN-RANGE REFRIGERATOR, STANDARD REFRIGERATOR, NO-FROST REFRIGERATOR-FREEZER, STANDARD REFRIGERATOR-FREEZER, NO-FROST FREEZER, STANDARD FREEZER, NO-FROST
• ENTERTAINMENT	BLACK & WHITE TV, STANDARD BLACK & WHITE TV, INSTANT-ON COLOR TV, STANDARD COLOR TV, INSTANT-ON RADIO RADIO-PHONOGRAPH
• LIGHTING	INCANDESCENT LIGHT FLUORESCENT LIGHT YARD LIGHT
• APPLIANCES	MANY

3 (commercial), 4 (industrial), and 5 (transportation).

A set of elements (and their documentation) is associated with each energy supply or utilization process. The set of elements defined for the current supply technologies and end-use demands are tabulated in Figures 6 and 7. Additional elements have been defined for some of the recently entered future supply technologies. All elements for supply processes (except the Efficiency Factors) are given in appropriate units per 10^{12} Btu flow into the process and for utilization processes in appropriate units per energy demand measure (dwelling, passenger-mile, ton of product, etc.).

For purposes of model sensitivity analysis, a "quality measure" has been included for each element in the data base. Since the nature of the data does not permit assignment of a conventional uncertainty measure (plus/minus numeric error, high-low uncertainty range, etc.) the data compilers have provided a judgmental "hardness" number for each value as a computer-recognizable quality measure. These hardness numbers range from 1 to 5 and have the following definitions:

<u>Hardness</u>	<u>Definition</u>
1	Very good. Highest confidence. Error probably ≤ 10 percent. Data well accepted and verified.
2	Good. Reportable and accepted. Error probably ≤ 25 percent.
3	Fair. Validity may be uncertain due to method of combining or applying data. Error probably ≤ 50 percent.
4	Poor. Low confidence. Validity questionable. Error probably ≤ 100 percent.
5	Very poor. Validity unknown. Error may be as high as an order of magnitude.

Documentation is provided in the EMDB for each element in the form of references and footnotes. A list of references documents

Figure 3

EMDB COMMERCIAL ENERGY DEMANDS

ACTIVITY	PROCESS
• SPACE CONDITIONING	SPACE HEATER ELECTRIC AIR CONDITIONER GAS AIR CONDITIONER
• WATER HEATING	WATER HEATER
• KITCHEN	COOKING UNIT STANDARD REFRIGERATOR-FREEZER
• LIGHTING	INDOOR LIGHTS STREET LIGHTS
• APPLIANCES	MISCELLANEOUS APPLIANCES
• FEEDSTOCK	ROAD MATERIAL

Figure 4

EMDB INDUSTRIAL ENERGY DEMANDS

- SIC 26
 - PAPER AND PULP MILLS
 - PAPER PRODUCTS MANUFACTURE
- SIC 37
 - MOTOR VEHICLES
 - MOTOR VEHICLE PARTS
- SIC 32
 - GLASS PRODUCTS
 - CLAY PRODUCTS
 - CEMENT AND RELATED PRODUCTS
 - STONE AND RELATED PRODUCTS
- SIC 28
 - INORGANIC CHEMICALS
 - ORGANIC CHEMICALS
- SIC 20
 - MEAT AND DAIRY PRODUCTS
 - BAKERY, SUGAR, CONFECTIONERY
 - BEVERAGE, CAN, CURED, FROZEN
 - GRAIN MILL AND MISCELLANEOUS FOODS
- SIC 33
 - IRON AND STEEL MAKING
 - IRON AND STEEL CASTINGS
 - PRIMARY ALUMINUM
 - PRIMARY COPPER
 - PRIMARY ZINC

Figure 5

EMDB TRANSPORTATION ENERGY DEMANDS

ACTIVITY	PROCESS
FREIGHT	BARGE SHIP TRUCK RAILROAD DOMESTIC AIRLINE INTERNATIONAL AIRLINE
• PASSENGER	DOMESTIC AIRLINE INTERNATIONAL AIRLINE INTERCITY AUTOMOBILE URBAN AUTOMOBILE INTERCITY BUS URBAN BUS MOTORCYCLE RECREATION BOAT GENERAL AVIATION RAILROAD URBAN RAIL RAPID TRANSIT
• MILITARY, GOVERNMENT	GROUND VEHICLES AIRCRAFT, PISTON AIRCRAFT, TURBINE JET SHIP

Figure 6

EMDB PROCESS ELEMENTS (CURRENT TECHNOLOGIES)

- EFFICIENCY FACTORS
 - MARKET ALLOCATION
 - PRIMARY EFFICIENCY
 - PRIMARY FUEL FRACTIONS
 - ANCILLARY FUEL FRACTIONS
 - ANCILLARY ENERGY
 - ENERGY DEMAND
 - ENERGY DEMAND MEASURE
- WATER EMISSIONS
 - ACIDS
 - BASES
 - PO₄
 - NO₄
 - OTHER DISSOLVED SOLIDS
 - TOTAL DISSOLVED SOLIDS
 - SUSPENDED SOLIDS
 - NON-DEGRADABLE ORGANICS
 - BOD
 - COD
 - THERMAL
- AIR EMISSIONS
 - PARTICULATES
 - NO_x
 - SO_x
 - HYDROCARBONS
 - CO
 - CO₂
 - ALDEHYDES, ETC.
- SOLID WASTE & LAND USE
 - SOLID WASTE
 - LAND
- HEALTH DATA
 - OCCUPATIONAL DEATHS
 - OCCUPATIONAL INJURIES
 - OCCUPATIONAL MAN-DAYS LOST

Figure 7

EMDB PROCESS ELEMENTS

(CONT'D)

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

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

the sources from which the individual number was taken or from which information was derived by which the element value (or its quality measure) was calculated, derived, estimated, etc. The footnotes contain textual information detailing assumptions made, calculational techniques used, etc. in order to derive the element value or its quality measure. Each reference or footnote is assigned an identification number which is linked to each particular element to which it refers.

A sample output for a process, in a "people-readable" format, is shown in figure 8 and 9. The supply process is identified as to Resource (Coal), Activity (Distribution), Process (Unit Train), Region (National), and Control Level (Uncontrolled). A utilization process would be similarly identified as to Sector, Activity, Process, Fuel, and Control Level. There is a place reserved in which the history of variations made to process blocks through time can be recorded, dated for user convenience.

Figure 8

EMDB OUTPUT

COAL
DISTRIBUTION
UNIT TRAIN
NATIONAL
UNCONTROLLED

DATA ELEMENT	VALUE	UNITS	QUAL

* MARKET ALLOCATION	5.280E-01		1
* PRIMARY EFFICIENCY	1.000E+00		2
* PRIMARY FUEL, PHYSICAL LOSS	N.A.		
* ANCILLARY FUEL, OIL	1.430E+10		2
* ANCILLARY FUEL, ELECTRICITY	1.030E+08		2
* ANCILLARY ENERGY, TOTAL	1.430E+10	BTU/10E12 BTU(IN)	4
* PARTICULATES	1.770E+01	TONS/10E12 BTU(IN)	4
* OXIDES OF NITROGEN	3.860E+00	TONS/10E12 BTU(IN)	3
* OXIDES OF SULFUR	3.350E+00	TONS/10E12 BTU(IN)	3
* HYDROCARBONS	2.560E+00	TONS/10E12 BTU(IN)	3
* CARBON MONOXIDE	3.610E+00	TONS/10E12 BTU(IN)	3
* ALDEHYDES, ETC.	5.670E-01	TONS/10E12 BTU(IN)	3
* TOTAL AIR POLLUTANTS	3.160E+01	TONS/10E12 BTU(IN)	3
* LAND USE	3.390E+01	ACRES/10E12 BTU(IN)	2
* OCCUPATIONAL DEATHS	6.100E-02	NUMBER/10E12 BTU(IN)	2
* OCCUPATIONAL INJURIES	5.850E-01	NUMBER/10E12 BTU(IN)	2
* OCCUPATIONAL MAN DAYS LOST	5.950E+01	NUMBER/10E12 BTU(IN)	2
* FIXED COST	5.100E+03	DOLLARS/10E12 BTU(IN)	3
* OPERATING COST	7.980E+04	DOLLARS/10E12 BTU(IN)	3
* TOTAL COST	8.490E+04	DOLLARS/10E12 BTU(IN)	2

DATA ELEMENT	REF#	DATA ELEMENT	FTN#
***		***	
* MARKET ALLOCATION	4015	* MARKET ALLOCATION	1719
* PRIMARY EFFICIENCY	2	* PRIMARY EFFICIENCY	1005
*	5	*	1006
*	21	*	1007
*	23	*	1008
*	1004	*	1801
*	1005	* PRIMARY FUEL, PHYSICAL LOSS	
*	1006	* ANCILLARY FUEL, OIL	1720
*	1013	* ANCILLARY FUEL, ELECTRICITY	1721
*	1056	* ANCILLARY ENERGY, TOTAL	1005
* PRIMARY FUEL, PHYSICAL LOSS	4016	*	1005
* ANCILLARY FUEL, OIL	4017	*	1083
*	4018	* PARTICULATES	
* ANCILLARY FUEL, ELECTRICITY	2	* OXIDES OF NITROGEN	1005
* ANCILLARY ENERGY, TOTAL	5	* OXIDES OF SULFUR	1005
*	21	* HYDROCARBONS	1005
*	23	* CARBON MONOXIDE	1005
*	1004	* ALDEHYDES, ETC.	1005
*	1005	* TOTAL AIR POLLUTANTS	
*	1006	* LAND USE	1027
*	1056	* OCCUPATIONAL DEATHS	1033
* PARTICULATES	2	* OCCUPATIONAL INJURIES	1033
*	5	* OCCUPATIONAL MAN DAYS LOST	1033
*	21	* FIXED COST	1005
*	23	*	1044
*	1004	*	1045
*	1005	*	1052
*	1006	* OPERATING COST	1005

Figure 9

EMDB OUTPUT (CONT'D)

- REF#? 33
BUR OF ACCOUNTS, RAILROADS, TRANS. STAT. IN THE US. 1971, ICC,
1972.
- REF#? 1004
MINERAL INDUSTRY SURVEYS, COAL-BITUMINOUS + LIGNITE IN 1971.
U.S.D.I., BUR. OF MINES, SEPTEMBER, 1972.
- REF#? 1005
BITUMINOUS COAL FACTS, 1968, NATIONAL COAL ASSOCIATION, 1968.
- REF#? 1006
GLOVER, T.O., M.E. HINKLE, + H.L. RILEY, UNIT TRAIN TRANSPORTATION
OF COAL. U.S.D.I., BUR. OF MINES, IC 8444, 1970.
- REF#? 1013
COX, J. (U.S. BUR. OF MINES). PERSONAL COMMUNICATION. FEBRUARY,
1973.
- REF#? 1056
NELSON, J.K. AND R.J. FRANKEL, RESIDUALS MANAGEMENT IN THE COAL-
ENERGY INDUSTRY, UNPUBLISHED MANUSCRIPT, RESOURCES FOR THE
FUTURE, INC., WASH., D.C. (UNPUBLISHED 1973).
- REF#? 4015
COAL TRAFFIC ANNUAL 45 (1972).
- REF#? 4016
STATISTICAL ABSTRACT OF U.S., TABLE NO. 878, P. 547 (1971).
- REF#? 4017
STATISTICAL ABSTRACT OF U.S., TABLE NO. 875, P. 546 (1971).
- REF#? 4018
STATISTICAL ABSTRACT OF U.S., TABLE NO. 878, P. 547 (1971).
- FTN#? 1005
IN GENERAL, A UNIT TRAIN HAULS 10,000 T OF COAL PER TRIP (1005,33)

AND UTILIZES THE EQUIVALENT OF 4, 2400 HP DIESEL LOCOMOTIVES
(FROM DATA ON MATTHEWS MINE IN (1006)).
ENERGY CONSUMPTION BY FREIGHT TRAINS, ASSUMED TO APPLY AS
WELL TO UNIT TRAINS, IS 690 BTU/TMI (FOOTNOTE 7013), OR
0.005 GAL DIESEL FUEL/TMI (5.86E6 BTU/BBL, 0005,38).
AN ALL STEEL HOPPER CAR WITH A CAPACITY OF 70 T HAS A GROSS TO
TARE WEIGHT RATIO OF ABOUT 4/1 (0023,1136). IT IS ASSUMED THAT
THIS FIGURE HOLDS FOR 100 T CARS AND THAT THE FUEL CONSUMPTION
PER TRAIN IS AS CITED ABOVE. FROM DATA IN (0021,31) THE ENERGY
CONSUMPTION ASSUMES AN AVERAGE USAGE OF 3 LOCOMOTIVES PER
TRAIN.
THE AVERAGE HAULAGE DISTANCE IS 300 MI (1005,96). HENCE, FUEL
CONSUMPTION IS 25,000 GAL PER ROUND TRIP OR 1.03E5 GAL/1.0E12
BTU. THE EMISSION FACTORS ARE COMPUTED FROM (0002,3-7).
WINDAGE LOSSES, ASSUMED TO BE AIRBORNE AS PARTICULATES, ARE
ABOUT 1P OF THE TONNAGE HAULED. SINCE THE LOSSES OCCUR MAINLY
DURING HANDLING AT EITHER ENDPOINT, THEY ARE ESSENTIALLY
INDEPENDENT OF THE HAULAGE DISTANCE (1056,IV-45). THUS, 410 T
OF COAL FINES ARE RELEASED AS PARTICULATES FOR EACH 1.0E12 BTU
HAULED.

NOTE HAULAGE BY UNIT TRAIN ACCOUNTS FOR 22P OF THE TOTAL COAL
MOVEMENT (1004,54).

- FTN#? 1006
THE AVERAGE CAPACITY OF A BARGE IS 25,000 T (1005,34), AND THE
AVERAGE HAULAGE DISTANCE IS ASSUMED TO BE 300 MI. THE EMISSION
IS CALCULATED FROM DATA ON MOTORSHIPS UNDERWAY IN (0002,3-11).
THE WINDAGE LOSSES, OCCURRING MAINLY FROM HANDLING AT THE
ORIGIN AND TERMINAL POINTS, ARE ASSUMED TO BE 1P OF THE TOTAL
SHIPMENT AS IN THE CASE FOR UNIT TRAINS. THUS, 410 T OF COAL
FINES ARE EMITTED AS PARTICULATES. (FOOTNOTE 1005)

MODEL INTERFACING

To supplement the utility of the EMDB for use in modeling calculations, the network of processes in the energy system has been structured into a set of links and nodes which completely define the flow through the network. With this link-node structure, all trajectories connecting specific resources to specific end-uses can be defined for all or any part of the national energy system. The links have been identified with the basic process units in the EMDB, and any or all of the values in each unit can be associated with the proper link. Two programs, one called the Energy System Network Simulator (ESNS) and the other called the Energy System Generator (ESYG), have been developed (each serving a different purpose) to calculate energy flows and to sum up effects through any desired set of sub-systems or set of trajectories under different assumptions of growth rate, conservation policy, technological change, etc., allowing the impact of various policy options to be determined.

Figure 10 shows the supply process network for the ESNS flow model for the fossil fuel sub-systems, including an array of future fossil energy technologies, such as coal gasification, liquefaction, and methanol production, and shale oil development. The nuclear contribution to the national energy supply system, noted in two simple links in the upper right-hand corner, has been developed into a full set of process links defining the complete nuclear fuel cycle. The documented numeric data for this sub-system are already in the data base. Sub-systems for geothermal and solar energy have also been prepared, and the process data have been collected, documented and inserted into the EMDB. Examination of the figure will give some idea of the richness of technological detail available in the EMDB. It should be noted that most of the current technology supply processes

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are represented by a number of blocks. These represent the differences resulting from regional characteristics of the resource or from the emission control strategy employed. For example, coals representing national average, northwest, southwest, central, northern Appalachian and central Appalachian coals are separately given. Likewise, environmental emission controls are given, when available, for both current standard practice (UNCONTROLLED) and for full application of best available controls (CONTROLLED).

For many policy applications, the level of detail involved in the full ESNS process network is not needed. Figure 11 displays a network in which the processes for a given supply activity have been aggregated to the level of that activity, i.e., there is only one link for the transport of crude oil rather than the five (pipeline, tanker, barge, etc.) of the process-level network. The utilization processes have been aggregated to the same set of end-use demands which drive the Brookhaven Reference Energy System. The input data for this network are not listed or documented in the EMDB since they are simply the weighted sum of the element values from the data base for all of the process included in the activity.

With either the full process-level network or the simplified activity-level network, the ESNS model provides the capability to explore a vast array of user-provided energy system modifications swiftly. Availability of an interactive program, called Interactive Remote Access To ESNS (IRATE), allows use of the model by those who have only a minimal acquaintance with computers.

NATIONAL ENERGY SYSTEM NETWORK FOR ESS MODEL

Figure 11