Section 7

CONCLUSION

This exploratory study into the feasibility of integrating water resources constraints into energy models may be summarized as follows:

- In order to represent in a meaningful way the potential interactions between the energy and water sectors of the U.S., it is necessary to use a model aggregated at most to the regional level. For this reason, the BNL model, RESOM, was selected and was modified to yield the WATER-RESOM variant. Similarly, the EPM model of LLL was adjusted so as to beocme WATER-EPM.

- Integration of water constraints into regionalized energy-economy models is both relevant and feasible. Models including representations of water availability and coefficients of water uses may be useful for studying potential interactions between the energy and water sectors of the U.S., and for evaluating the effects of such interactions on the rest of the economy.

- It appears that future studies of the water-energy interface in the U.S. should focus on more accurate regionalized models, so as to estimate the time when, under certain conditions water-energy issues may become acute in a given region, and to rank the regions in this fashion. Following this ranking process, the effort could be concentrated in the regions where these problems will arise sooner, so as to quantify the issues involved in the energy-nonenergy conflicting requirements for a finite amount of water, and to derive alternative policies for the management and use of these important resources.

- Future studies of water-energy interactions should include analyses and evaluations of policy alternatives available in the various regions regarding the development, allocation, and use of water resources. One such study could focus for example, on water transfers from current users in the nonenergy sector to potential users in the energy sector, and the economic, political, and social implications of such transfers.

- The current study related only to water quantity. Water quality management may become, in specific areas, a major issue since it could be affected considerably by energy-related activities.

- A strictly deterministic point of view was adopted in this study. The stochastic aspects of streamflow and water availability need to be included in the analyses of policy options regarding the development, allocation, and use of water within water-energy-economy modeling efforts.

- The effect of technolgy improvements, in water production (e.g., saline water desalination), in nonenergy water use (e.g., more efficient irrigation), and in energy-related activities (e.g., water-saving cooling techniques), need to be considered when looking at water constrained futures.

- This exploratory study restricted itself to deterministic representations of water resources. A more realistic approach is to consider the stochastic aspects of water availability and to include them in analyses of policy options.

- Water quantity alone was considered in this study. However, water quality may become a central issue in specific areas, as a consequence of energy-related activities.

Section 8

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Appendix A

GLOSSARY

Aquifer. A geological formation bearing and conveying water. Water contained in an aquifer is called groundwater. Groundwater saturates the pore space of the aquifer. The upper boundary of the saturated zone of an aquifer is called water table. Aquifers may be overlaid with impervious material (e.g., clay layers) and the water contained in them connected with water bodies at higher elevations. Under these conditions, the aquifer is confined and groundwater is under pressure. The level to which groundwater would rise if the pressure were released defines the piezometric surface. When the piezometric surface is higher than ground surface, the aquifer is artesian.

Blowdown. River, lake, and groundwater contain dissolved salts. Use of these waters in evaporative processes tends to increase salt concentration in the remaining water. Removal of the resulting brine is blowdown.

Consumptive use. Use of water so that it becomes unavailable for further uses within the same hydrological unit. Water is consumptively used when incorporated in a product (e.g., canning fruit and vegetables), when evaporated for removal of waste heat, or when removing waste material (waste water). Thus consumptive use may result in a decrease of water quantity and/or degradation of water quality.

Groundwater. See aquifer.

Groundwater overdraft. Water may be pumped from aquifers in a groundwater basin at various rates. The amount of water which can be withdrawn annually without causing an undesirable influence in the basin (e.g., lowering water tables below a given elevation) is called safe yield. Pumping of groundwater in excess of safe yield is overdraft.

Instream flow. Includes flow requirements for navigation, hydroelectric power generation, conveyance to meet downstream treaty and compact commitments, fish and wildlife habitat maintenance, waste assimilation, recreation, sediment transport and fresh water inflow to estuaries (see Figure A-1).

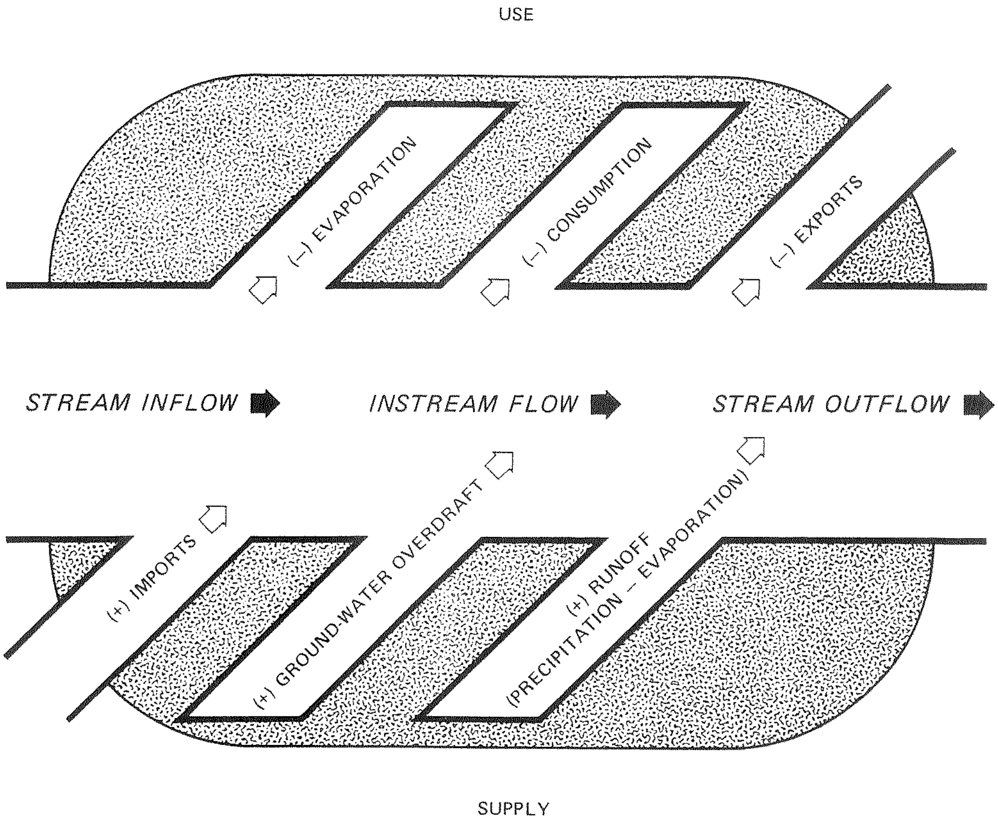

Figure A-1. Schematic Representation of Regional Water Balance

Makeup water. 1. Water added to steam generating facilities to replace steam which escaped or was wented to atmosphere (boiler makeup). 2. Water added to evaporative cooling facilities using water.

Piezometric surface. See aquifer.

Potable water. Water of drinking water quality with respect to physical, chemical and bacteriological properties. Usually it includes water for drinking, cooking, washing, bathing, laundering, and toilet flushing.

Process water. Water incorporated in a product, either wholly (i.e., the entire water molecule), or partially (e.g., the hydrogen of the water molecule is used in the hydrogenation of synthetic fuels). See also consumptive use.

Raw water. Total amount of water supplied to an industrial plant or to a steam-electric generating facility. Often raw waters are treated chemically (e.g., softened), to make them suitable for use. Some water losses may occur in this treatment.

Return flow. See withdrawal.

River basin. A geographical area enclosed by a fictitious line such that all precipitation falling within it and flowing on its surface reaches the lowest point of the ground surface. Also called drainage basin, or catchment area. See also runoff.

Runoff. Precipitation less natural evaporation from land surfaces, less plant evapotranspiration, less percolation to groundwater. Runoff is usually expressed quantitatively in relation to a river basin.

Stream inflow. Amount of water entering a water resources region through a river (or rivers).

Streamflow. Amount of water flowing in a river.

Streamflow frequency. Variations in annual streamflow are expressed in terms of flow that is expected to be exceeded in a specific percentage of years. For example, a flow of 5-percent exceedance represents a very high flow that will be exceeded in only 5 out of 100 years, on the average.

Waste water. See consumptive use.

Water balance. A regional accounting of water inflows, outflows, uses, and changes in storage, so as to reflect the law of conservation of matter.

Water table. See aquifer.

Withdrawal. Water abstracted from a supply source (surface or groundwater). Part of the withdrawal water is consumed; part may evaporate without an apparent beneficial use; and part may reappear in streams (or aquifers) as return flow.

Appendix B

CONVERSION FACTORS

Water Measurement

Quantity

1 acre-foot = 325,851 gallons
= 43,560 cubic feet

1 million gallons = 3.07 acre-feet

1 cubic foot = 7.48 gallons

Flow

1 million gallons per day (mgd) = 694.4 gallons per minute (gpm)
= 1.55 cubic feet per second (cfs)
= 1,120 acre-feet per year (ac-ft/yr)

1 billion gallons per day (bgd) = 1.12 million acre-feet per year (Maf/yr)

1 cubic foot per second = 1.98 acre-feet per day

Energy

1 British thermal unit (Btu) = 1.05506 kilo Joules (kJ)

1 kilowatt-hour (kWh) = 3,600 kilo Joules (kJ)

Water and Energy

Million acre-feet per 10^{15} (quad) Btu = 1.11174 gallons per kilowatt-hour

Appendix C

ESTIMATED CHARACTERISTICS OF SOME ENERGY-RELATED TECHNOLOGIES

Table C-1

COAL LIQUEFACTION PROCESSES

Required power generated at the liquefaction plant

Characteristic	Case 1 (SRC)	Case 2 (CHL)	Case 3 (SRC)	Case 4 (CHL)
Overall thermal efficiency[a] (%)	71.8	67.7	69.9	65.0
Electric power requirements (MW)	182	238	205	317
Capital requirement (10^6 1976\$)	1,510	1,690	1,612	1,985
Operating manpower	204	213	209	226
Production costs (1976\$/10^6 Btu)	4.54	5.32	4.79	5.87

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[a] Fuel products/total coal feed

Source: McNamee et al. 1978

Table C-2

COMPARISON OF POWER AND CAPITAL REQUIREMENTS FOR COAL LIQUEFACTION: REQUIRED POWER GENERATED AT THE PLANT OR PURCHASED OUTSIDE

Characteristic	Case 1 (SRC)	Case 1A (electric drive)	Case 1A1 (steam drive)
Electric power (MW)			
Generated	182	86.86	0
Purchased	0	102.14	99
Total	182	189.00	99
Capital (10^6 1976\$)	1,510	1,345	1,268
Production costs (1976\$/10^6 Btu)	4.54	4.44	4.26

Source: McNamee et al. 1978.

Table C-3

COAL GASIFICATION PLANTS[a]
10,000 tons coal per day

Characteristic	MACW	MX	FA	FX	EALC	EXL
Net fuel gas (10^6 Btu/day)	134,375	131,880	184,872	201,432	185,664	196,920
Liquid hydrocarbons (10^6 Btu/day)	23,168	22,738	31,874	34,730	32,011	33,952
Power by-product (MW)	76.4	63.7	72.5	50.2	106.0	---
Potential power from products (MW)	723.6	712.0	885.9	932.6	859.6	911.7
Total power (MW)	800.0	775.7	958.4	982.8	965.6	911.7
Capital (10^3 1975$)						
70% operating factor	521,501	625,241	409,123	398,271	363,260	346,059
90% operating factor	526,087	629,729	413,562	402,514	367,951	349,927
Operating labor per shift (people)	56	60	48	51	47	46
Production costs (1975$/$10^6$ Btu)						
70% operating factor	3.78	4.42	2.79	2.61	2.48	2.69
90% operating factor	3.19	3.71	2.40	2.26	2.13	2.38

Source: Kimmel et al. 1976.

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[a] For a key to symbols, see Table 3-4.

Table C-4

LOW-Btu COAL GASIFICATION COMBINED-CYCLE SYSTEMS FOR ELECTRIC POWER GENERATION[a]

Characteristic	MACW	MXSC	EAHC	EXHC	EALC	EXTC-SF	EXTC-DF
Overall efficiency (%)	35.0	40.6	40.5	38.5	38.1	38.7	38.2
Capital (1976$/kW)	905.67	711.12	705.15	738.55	930.67	816.53	854.00
Net power (MW)	988	1,212	1,214	1,149	1,138	1,157	1,142
Operating labor per shift (people)	36	30	27	28	27	28	28
Coal (ton/day)	13,900	10,000	10,000	10,000	10,000	10,000	10,000
Production costs (1976 mills/kWh)							
Coal ($\$1/10^6$ Btu)	41.20	32.79	32.53	34.05	41.35	37.21	38.25
Coal ($\$2/10^6$ Btu)	51.38	41.57	41.32	43.30	50.69	46.47	47.56

Sources: McElmurry 1977, Chandra et al. 1978.

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[a] For a key to symbols, see Table 3-4. SF indicates slurry feed of coal; DF direct (dry) feed of coal.

Appendix D

EPM -- AN ENERGY POLICY MODEL

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Energy & Resource Planning
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The Lawrence Livermore Laboratory (LLL) uses its Energy Policy Model (EPM) not only to project equilibrium prices and quantities over a long-term horizon (usually 50 years) under free market conditions, but also to exhibit the effects of government policies and other constraints on free market economics. Like the SRI-Gulf Model, from which much of its structure is derived, EPM is a dynamic regionalized model of the energy sector of the U.S. economy in which energy flows are conceptualized as a network with resource nodes at the bottom and end-use nodes at the top. Energy flows upward through a variety of process and transportation nodes. A sample network branch is shown in Figure D-1.

The regionalization in EPM requires distinct nodes for all processes (oil refining, power generation, etc.) and all materials (coal, gasoline, etc.) in every region, as well as for various forms of interregional transport of materials. End-use demands for transportation, space heat, etc. are aggregated by U.S. census regions while resource regions are defined where needed for coal, crude oil, shale deposits, etc. Input data include or imply supply curves at production nodes, demand curves at end-use nodes, and parameters for determining costs and efficiencies at process and transportation nodes.

The use of EPM in a study usually requires the development of a problem-specific version reflecting a suitable base-case scenario. This development may include modification of the network to provide more detail in a sector, such as transportation, or a region, such as New England. Once a basic version has been run, additional scenarios can be designed to reflect assumptions about the economics of any process, e.g., power generated by a coal-fired boiler, about government policies regarding price controls or import limitations, about the dates on which new technologies will be available, etc. The implementation of alternative

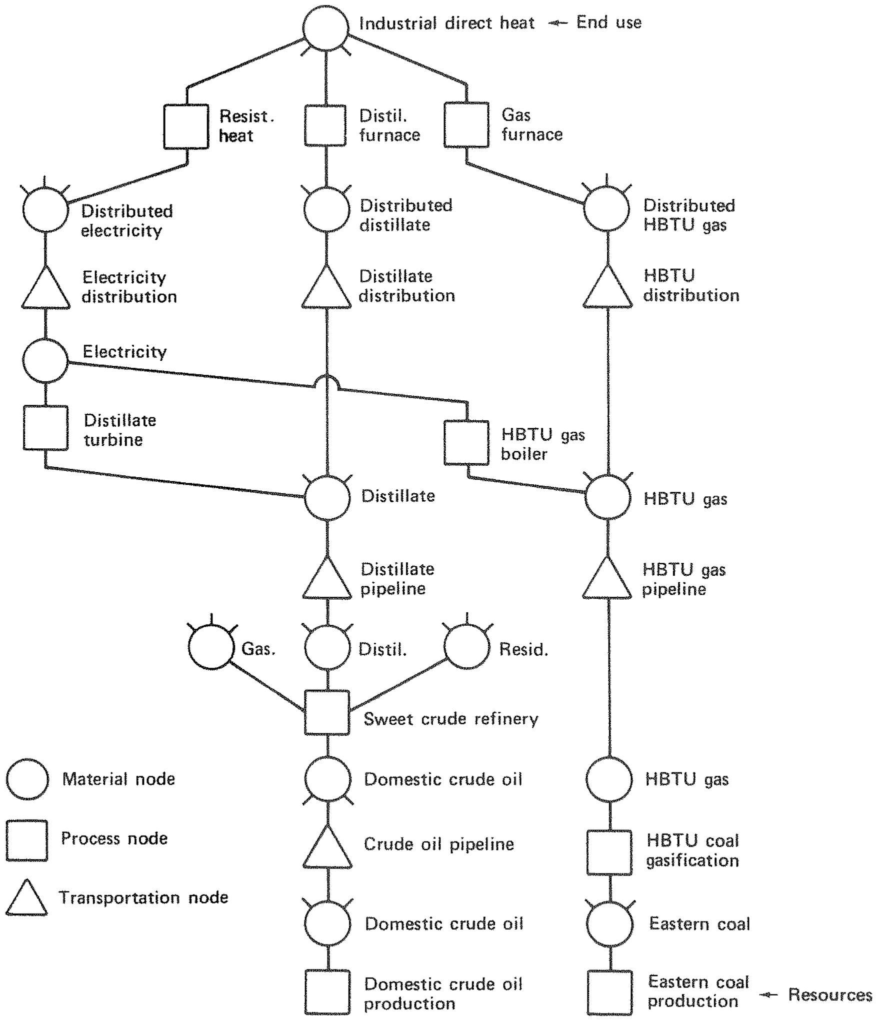


Figure D-1. A Sample Network Section Showing Energy Plan From Resources to End-uses scenarios is accomplished by changing the appropriate parameters in the base version and re-running the model. In any run of EPM, market clearing prices and quantities for a network of several thousand nodes are determined dynamically over a 50-year time horizon.

In order to facilitate the construction and use of EPM, LLL developed an Economic Modeling System (EMS), which consists of four distinct computer programs, INPUT, SOLVE, PRINT, and PLOT along with a specialized modeling language. The program INPUT requires two files -- a network file and parameter file -- to produce an initial market structure. The network file describes energy flows in the symbolic language that INPUT recognizes, while the parameter file provides all necessary data. INPUT generates a market structure, a sequenced network of market, process, and transportation nodes with fully specified calculational routines attached to the nodes. This preliminary market structure, which is dumped as the work file WORKA, contains only initializations, usually zero, of the prices and quantities that will appear in all subsequent market structures.

Program SOLVE takes WORKA, which includes initializing estimates of the volume of resource production, and works up the network from resources to end-uses computing prices, and then down again computing quantities. It thus produces a new market structure which includes prices and quantities at all market nodes. Each such round-trip through the network constitutes an iteration. If SOLVE has been asked to run 10 iterations, it will write over each market structure except the 10th, which it will dump as WORKB. If it is then re-started and run for 20 iterations, it will output the 30th market structure as WORKC. Techniques to drive toward an equilibrium of market clearing prices and quantities are built into SOLVE.

To illustrate the basic iterative process that leads to equilibrium, let us telescope a section of the network and hypothesize a process (Figure D-2a) with constant costs and efficiency:

- A is a resource material with a supply curve S_A exhibiting the quantity q_A of A that will be supplied at price p_A;
- A2B is a process transforming A to B with efficiency e $(0 < e < 1)$ at a cost of c dollars/10^6 Btu of product;
- B is an end-use material with demand curve D_B showing the quantity q_B which users will purchase if the price is p_B.

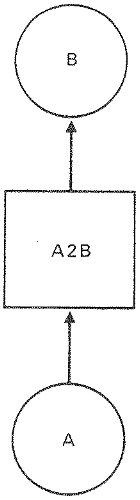


Figure D-2A. Feedstock A is Processed into Product B with Efficiency e and Cost of c Dollars per 10^6 Btu of Product

The supply curve S_A induces S_B (Figure D2b), a supply curve for B showing what may be thought of as the marginal costs (or the selling prices) of various quantities of B in a case where the owner of feedstock A also owns the A2B processor and thus supplies B rather than A. A point (q_A, p_A) on S_A maps into a point (q_B, p_B) on S_B as follows: When feedstock q_A is processed by A2B, which has efficiency e, the output q_B is $e \cdot q_A$. The price p_B will reflect the cost of the feedstock, which is p_A/e per unit of product, plus the processing cost c. Thus $q_B = e\, q_A$ and $p_B = c + p_A/e$.

Similarly, D_B induces D_A, a demand curve on the amounts of A needed to meet requirements on B. It may be thought of as describing the amounts of A that would be purchased at various prices by end users who could process it into B themselves with efficiency e and cost c.

If the mappings from S_A to S_B and from D_B to D_A are well-behaved, as is certainly the case with e and c assumed constant, then the equilibrium points (q_A, p_A) and (q_B, p_B) shown in Figure D-3 are equivalent. A highly simplified and static conceptualization of the iterative process leading to the equilibrium will now be described.

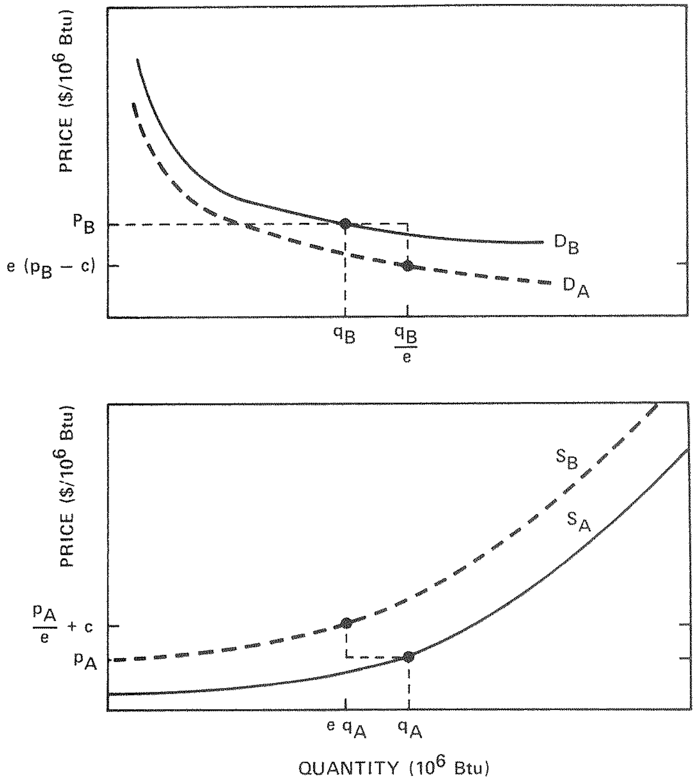


Figure D-2B. The Demand Function for the Product (D_B) Induces a Demand Function for the Feedstock. Likewise the Supply Function for the Feedstock (S_A) Induces a Supply Function for the Product

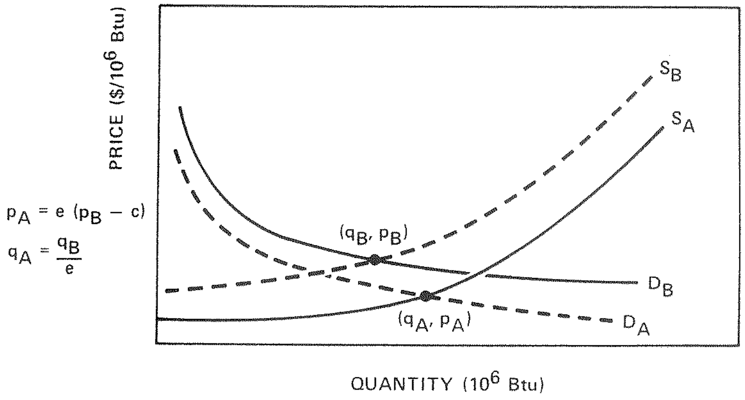


Figure D-3. The Feedstock Equilibrium $(q_A \cdot p_A)$ corresponds to the Product Equilibrium $(q_B \cdot p_B)$

The process is initialized with an estimate q_A of the production volume of the resource material A. The curve S_A then determines a price p_A, which is transformed during the upward portion of an iteration into a price $p_B = c + p_A/e$.

As prescribed by D_B, this price p_B determines a product demand quantity q_B, which is then transformed down the network to $q_A = q_B/e$, the quantity of feedstock demanded at price p_A. This concludes the first iteration. If, after some iteration, q_A' equals q_A, then the equilibrium point where D_A and S_A intersect has been found. In actual practice, one iterates until prices and quantities are sufficiently stable. This is done by setting $q_A = q_A'$ and repeating the process of determining p_A from S_A, working up to (q_B, p_B), etc.

Any work file can be passed to program PRINT or program PLOT, each of which transforms the market structure prices and quantities into a file suitable for displaying results.

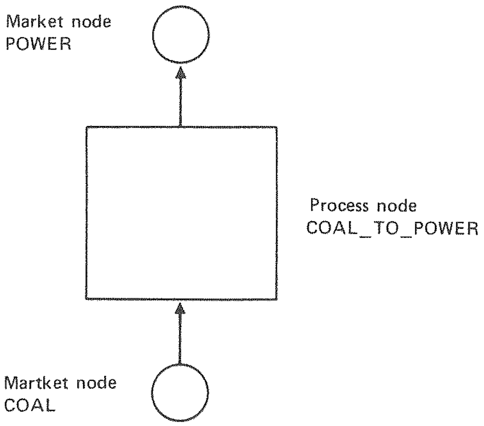
The output from PRINT provides, for each node and time period, the prices and quantities in the current market structure. The first line is prices in dollars/10^6 Btu; the second is energy measured in 10^6 Btu. The output from PLOT consists of graphs exhibiting, over the whole time horizon, either prices or quantities of single or aggregated materials. Examples are presented in the body of this paper (Figures 6-4 through 6-8).

The network file that must be provided to INPUT describes each process (square nodes) in the form:

```
PROCESS PROCESSNAME (FEEDSTOCK; PRODUCT)
```

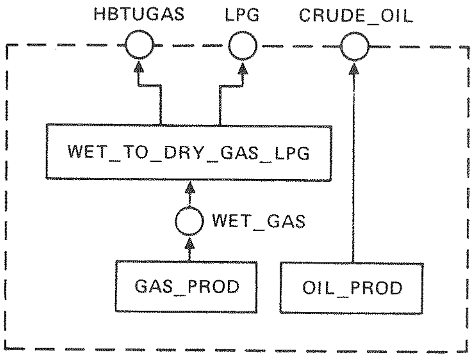
as shown in Figure D-4. Materials (circular nodes) are defined by their mention as inputs (feedstocks) or outputs (products) of processes. If no feedstock appears before the semicolon, the process is an input-free resource or raw material node such as coal-mining.

While all processes could be linked in one large model, the regionalization capabilities of EMS are best exploited through the use of sub-models which group the processes as in Figure D-5. The parameter list in the "DEFINE" line consists of material nodes capable of linkage outside the sub-model. The "MARKET RESOURCE" line lists all pertinent material (circular) nodes. Note that two of the processes are "production"as described above.



```
PROCESS COAL_TO_POWER (COAL; POWER)
```

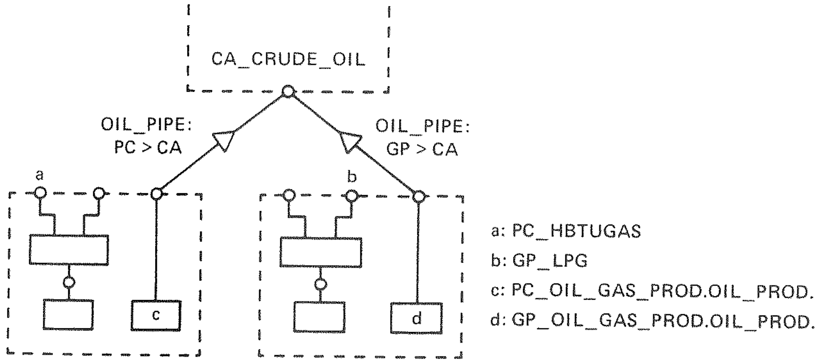
Figure D-4. One Statement Explicitly Defines a Process Node and Implicitly Defines Inputs and Outputs. The Above Statement and Diagram Represent the Generation of Electricity in a Coal-Fired Power Plant



```
DEFINE MODEL OIL_GAS_PROD (CRUDE_OIL, HBTUGAS, LPG)
  MARKET RESOURCE (WET_GAS_, CRUDE_OIL, HBTUGAS, LPG)
    PROCESS OIL_PROD (;CRUDE_OIL)
    PROCESS GAS_PROD (;WET_GAS)
    PROCESS WET_TO_DRY_GAS_LPG (WET_GAS; HBTUGAS, LPG)
END
```

Figure D-5. A Typical Submodel Describes Related Processes Occuring Together Within one or More Regions

The main model includes calls to all the sub-models and specification of each transportation link with a line that gives the type of transport, the regionalized names of the input and output materials, and abbreviations for the starting and destination points. An excerpt from a main model is given in Figure D-6.



```
CALL OIL_GAS_PROD:PC_OIL_GAS_PROD (PC_CRUDE_OIL,
      PC_HBTUGAS, PC_LPG)
CALL OIL_GAS_PROD:GP_OIL_GAS_PROD (GP_CRUDE_OIL,
      GP_HBTUGAS, GP_LPG)
TRANSPORTATION OIL_PIPE (PC_CRUDE_OIL; CA_CRUDE_OIL;
      PC > CA)
TRANSPORTATION OIL_PIPE (GP_CRUDE_OIL; CA_CRUDE_OIL;
      GP > CA)
```

Figure D-6. Oil and Gas Production in the Pacific Coast (PC) and Great Plains (GP) Resource Regions Provide Crude Oil Which is Piped to California (CA), a Refinery Region. The Main Model Contains Transportation Links and Calls to Regionalized Sub-models.

To each node in the network we must associate a calculational subroutine of a KIND recognized by EMS. In the parameter file each node defined in the network file must be classified as to KIND and the parameters required for that KIND must be supplied. Not only is a simple input format provided, but EMS allows multiple options for electing default values and simultaneously setting parameters for a class of similar nodes. These node-related sub-routines provide the means of calculating costs and efficiencies at each node and are thus the mechanism by which SOLVE calculates a price at each node when iterating upward and a quantity at each node when iterating downward.

Although designed with energy policy applications in mind, EMS has the potential for generating economic networks in a variety of contexts. Many capabilities not discussed above are in fact built into the software, including price and quantity controls, time lags, technological change and learning. The manner in which energy users and processers allocate demand among alternative suppliers and technologies is explicitly modeled.

All calculations are made dynamically, essentially simultaneously for all time periods. Thus, for example, prices in later time periods are influenced by the depletion level induced by quantities produced in previous periods, while capital investment decisions in early periods reflect an ability to project future inflation and prices and to discount to present value. Detailed documentation of the workings of EMS is available in LLL publications. [Rambo and Coles, 1978; Rousseau et al. 1978a, 1978b; Sussman and Rousseau 1978a, 1978b.]

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1. J.T. Rambo and B.L. Coles, 1978, User's Manual for the Livermore Economic Modeling System, Lawrence Livermore Laboratory, Report UCRL-52526.
2. W.F. Rousseau, J.T. Rambo, R.N. Castleton, and S.S. Sussman, 1978a, Computer Code Documentation for the Livermore Economic Modeling System, Lawrence Livermore Laboratory, Report UCRL-52519.
3. W.F. Rousseau, S.S. Sussman, R.N. Castleton, and J.T. Rambo, 1978b, Economic Models and Algorithms Used in the Livermore Economic Modeling System, Lawrence Livermore Laboratory, Report UCRL-52527.
4. S.S. Sussman and W.F. Rousseau, 1978a, A New Language for Economic General Equilibrium Models, Lawrence Livermore Laboratory, Report UCRL-52507.
5. S.S. Sussman and W.F. Rousseau, 1978b, A Demonstration of the Capabilities of the Livermore Energy Policy Model, Lawrence Livermore Laboratory, Report UCRL-52508.

Appendix E

WATER-RESOM SOFTWARE

The following is a list of software developed in conjunction with the WATER-RESOM model.

- WYL.WJ.NYB.MRESON1 -- a temporary report generator;
- WYL.WJ.NYB.UTILITY -- a library containing the following files:

  --COPY -- lists the problem data (stored on tape) on hard copy;

  --COPY1 -- moves problem data from tape to disk;

  --COPY2 -- moves problem data from disk to tape;

  --COPY3 -- moves data from FILE0004 on tape to FILE0003 on the same tape, thus making available FILE0004 for the latest data update yet keeping the previous data set on FILE0003;
- WYL.WJ.NYB.MRESON -- generates the dictionary section of MAGEN input data and includes commands for report generation based on the solution file of the MPS solver;
- WYL.WJ.NYB.MRESOM -- a copy of the MAGEN file as supplied by BNL;
- WYL.WJ.NYB.MRESON2 -- another temporary report generator;
- WYL.WJ.NYB.MRUN -- control statements for making an MPS run, including a report generator;
- WYL.WJ.NYB.MAGEN -- the job control statements of the MAGEN routine;
- WYL.WJ.NYB.MPSRUN -- control statements for making an MPS run without the generation of a report.

Listings of these computer programs are available on request.