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DOCUMENTATION OF THE BROOKHAVEN ENERGY
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^{6th}
² I-O AND ² I-O/BESOM LINKAGE

John T. Fraser

August 1978

Prepared for the
 ASSISTANT SECRETARY FOR POLICY AND EVALUATION
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I. INTRODUCTION

The purpose of this paper is to document the BNL input-output model and its linkage with the BNL linear activity analysis model, BESOM. In the BNL systems modeling approach, the I-O model provides an accounting framework for the estimation of functional end-use energy requirements, detailed capital and labor requirements, and material requirements. The BESOM model provides estimates of physical flows within the energy sector and the associated least-cost mix of energy supplies and conversion activities, given the appropriate inputs. The single-period optimization model, BESOM, is linked to the macroeconomy by incorporation of the BNL I-O model.⁶ Economic change and technological change may be represented in the GNP final demand vector and in the technical coefficients in the I-O matrix. Linking of the I-O and the LP models permits assessment of economy-wide impacts of future technological changes in both the energy sector and elsewhere in the economy as well as impacts arising from a wide range of government energy policies.

This paper describes the development and structure of the current version of the BNL I-O model presently in use and the structural modifications of a capital investment routine, and a balance of payments routine that have been incorporated. Also, the structure and solution techniques for the linked I-O/LP model are described.

II. BASIC I-O MODEL

A. Introduction

The interindustry structure of an I-O transactions matrix provides a significant degree of disaggregation. This permits detailed sectoral analysis within the context of the national economy. The I-O accounting

system is particularly useful in bridging the gap between the microstructure of each of the sectors and aggregates such as GNP and personal consumption expenditures.

The basic supply/demand balance in the I-O accounting framework is as follows:

$$(1) \quad AX + Y = X$$

where

A = the matrix of technical production coefficients,
X = a vector of gross outputs (domestic production),
Y = a vector of GNP final demands.

Rewriting this expression yields

$$(2) \quad Y = (I-A)X \text{ or } X = (I-A)^{-1} Y$$

This equation is the basis for determining the interindustry solution of sectoral outputs to meet final demands; i.e., the solution may be used to estimate the effects of a change in one or more of the final demand levels. Policy-induced changes in the structure of GNP final demand as well as behavioral economic changes can then be evaluated as to their effects on sectoral demands for output. In the $(I-A)^{-1}$ matrix the sum of column coefficients, a_{ij} , indicates the total increase in output for all industries that results from a given change in the final demand for industry j.

I-O Model Assumptions

The basic assumption associated with the I-O model is long-run equilibrium for future planning purposes. An I-O model constructed on historical data matches the state of the economy for the historical year, whether or not the economy was in long-run equilibrium. Sectoral growth rates

for the planning year under consideration are assumed to be at equilibrium. It is also assumed that factor inputs are perfectly mobile over the long run and that price expectations are in effect for a long enough period of time to permit complete factor input adjustment.

An additional point is that the data base is of historical vintage and that I-O coefficient estimates for 1985 studies are assumed to behave as augmented extrapolations of past trends; i.e., a base time trend structure. Specifically, all 1985 base-case estimates are tied to an assumed set of "business-as-usual" 1975-1985 policies and trends. This is to be interpreted, however, more as a reference point for comparison of alternative policies and trends rather than as a definitive prediction of the future. Specific sectoral estimate assumptions will be detailed in the section dealing with empirical estimation methodology for I-O coefficients.

B. BNL I-O Model

Historical Development

The present 110 sector I-O model employed by BNL is an expanded version of the original 101 sector I-O developed in collaboration with the Center for Advanced Computation at the University of Illinois. The original 101 sector model has been augmented to include new energy technologies in a 1985 time frame. The 101 sector was structured for analyses within a 1976-1980 time frame. The basic 101 sector model utilized historical 1967 BEA values for the A-matrix transaction coefficients, while the 110 sector model utilizes estimates of the 1985 transaction coefficients from the BLS. The present model incorporates time trended A-matrix coefficients as opposed to fixed coefficients over time.

Structural Characteristics

Several distinguishing characteristics of the BNL I-O model differentiate it from conventional interindustry I-O models. First, the BNL model is composed of energy and nonenergy sectors with the output of the energy sectors expressed in terms of physical Btu units instead of conventional constant or current dollar values. The nonenergy sector output is expressed in constant dollars. Second, outputs of the energy supply/conversion sectors are distributed to energy service sectors instead of directly to consuming sectors. The supply sectors convert and distribute raw fuels to sectors producing traditional energy forms, e.g., electricity and refined petroleum products; but they allow for nontraditional patterns, e.g., refined petroleum products from coal. The outputs of these energy supply/conversion sectors are then distributed to "dummy" energy product or service sectors.

This structure allows the specification of transactions in terms of fuels and end uses. The dummy energy product sectors define end-use demands for energy exhibiting a limited degree of substitutability; e.g., motive power, petrochemical feedstocks, coke, process heat, water heat, space heat, air conditioning, and electric power.

Finally, the framework of the BNL I-O model permits the addition of new energy technologies by the specification of appropriate production functions derived from engineering data and technical relationships. The functional end uses provide a basis for interfacing engineering concepts with economic behavior. By specifying energy input requirements to nonenergy sectors in terms of energy products, substitution among fuel supplies is permitted. Furthermore, technological change associated with

fuel substitution is captured in the production functions of the energy supply/conversion sectors.

The 110 sector model incorporates an expanded energy technology base within a 1985 framework. Specifically, five emerging energy technologies have been added as sectors: shale oil mining and retorting, high Btu coal gasification, high temperature gas reactor (HTGR) electric, low Btu coal gas combined cycle (gas/steam) electric, and solvent refined coal/steam electric. Additionally, the two I-O sectors in the 101 sector model, new construction and maintenance/ repair construction, have been disaggregated into seven sectors. Appendix I provides a cross-classification between the earlier 101 sector and the present 110 sector I-O models. In the 110 sector model, the energy supply/conversion sectors are designated as sectors 1 to 12 in the sectoral classification scheme. These sectors are composed of three basic supply sectors (1 to 3) - coal, crude oil and gas, and shale oil - and the conversion sectors (4 to 12). Sectoral definitions for these energy supply/conversion sectors are presented in Appendix II.

Figures 1A and 1B provide a representation of the I-O submatrices. The energy supply/conversion sector is more disaggregated in Figure 1A than in Figure 1B; i.e., the energy sectors R and C in Figure 1A are combined into sector S in Figure 1B. The energy sectors in Figure 1A are subdivided into three components: primary energy resources, R (e.g., coal, crude oil, and gas); converted energy resources C (e.g., refined oil products, pipeline gas); and energy products, P (e.g., space heat, motive power). In Figure 1B, by convention, sectors R and C of Figure 1A are

"A" MATRIX (INTERINDUSTRY COEFFICIENT)					FINAL DEMAND	TOTAL OUTPUT
	R	C	P	I		
ENERGY SUPPLY	R	A_{RC}	A_{RP}		Y_R	X_R
ENERGY CONVERSION	C		A_{CP}		Y_C	X_C
ENERGY PRODUCTS	P	A_{PR}	A_{PC}	A_{PI}	Y_P	X_P
NON-ENERGY SECTORS	I	A_{IR}	A_{IC}	A_{II}	Y_I	X_I

Figure 1A.

	S	P	I	FINAL DEMAND	TOTAL OUTPUT
	S	P	I		
S	A_{SS} BTU/BTU	A_{SP} BTU/BTU		Y_S 10^{13} BTU	X_S 10^{13} BTU
P	A_{PS} BTU/BTU		A_{PI} 10^6 BTU/\$	Y_P 10^{13} BTU	X_P 10^{13} BTU
I	A_{IS} \$/ 10^6 BTU		A_{II} \$/\$	Y_I 10^6 \$	X_I 10^6 \$

Figure 1B.

combined into the energy supply/conversion sectors. This latter format will be used in the remainder of this paper.

In Figure 1B, the A-matrix input-output coefficients for the energy and nonenergy sectors describe the service, materials, and other direct requirements from I-O sectors necessary to operate and maintain a producing plant for a period of one year. It should be noted briefly here that the output units of measurements for the energy sectors are in terms of Btu's, as indicated in Figure 1B, as opposed to the conventional measure of constant dollar value. The final demand vector, Y, and the total output vector, X, are similarly divided. Table 1 presents a basic definition of the A-matrix coefficients corresponding to the format of Figure 1B.

The model structure in Figure 1B indicates that the energy supply/conversion industries require inputs from all three basic categories -- energy supplies, energy products, and nonenergy products. This is indicated by the fact that all three submatrices of the supply/conversion column have positive values. The second column indicates that only energy supplies are used to produce energy products and the third column indicates that the nonenergy sectors do not require energy supplies -- only energy products and nonenergy inputs.

The units of measurement in Figure 1B indicate that all energy supply/conversion sector outputs and energy product outputs are measured in terms of Btu's whereas the nonenergy products are measured in the conventional constant dollars. The result is that coefficients between non-energy sectors are defined in dollars, between energy sectors in Btu's and

Table 1

A-Matrix Coefficients

A_{SS} = input-output coefficients describing sales of the output of one energy/supply conversion sector to another energy conversion sector and conversion losses incurred in producing or distributing energy.

A_{SP} = input-output coefficients describing how distributed energy products are converted to end use forms. They contain the end use conversion efficiencies embodied in the BESOM LP system described later in this paper.

A_{SI} = 0 implying that energy supplies are not used by non-energy producing sectors; energy products are used by the non-energy-producing sectors.

A_{PS} = input-output coefficients describing how energy products -- final energy forms -- are used by the energy-supplying industries. Included here would be electricity use for lighting a refinery.

A_{PP} = 0 implying that energy products are not used to produce energy products.

A_{PI} = input-output coefficients describing how energy products -- final energy forms -- are used by non-energy producing sectors. This submatrix describes the ways end-use energy forms are used in the non-energy producing sectors. Examples are blast furnace heating or space heating.

A_{IS} = input-output coefficients describing the uses of non-energy materials and services by the energy industry such as pipes or pumps.

A_{IP} = 0 implying energy product-sectors equipment require no material or service inputs. This is because they are pseudosectors and not real producing sectors.

A_{II} = input-output coefficients describing how nonenergy products are used in the non-energy producing sector. An example would be steel for golf clubs.

between nonenergy sectors and energy sectors in Btu per dollar or vice versa.

An important characteristic of this model structure is that substitution among fuel supplies is permitted by specification of input requirements in terms of energy products. The interfuel substitution effects are implemented by changing the coefficients linking the energy supply sectors to the energy product sectors; i.e., A_{SP} , and the energy supply sectors to themselves; i.e., A_{SS} . As an example, an increase in oil- and gas-fired electric generating plants relative to coal-fired plants can be represented by increasing the input coefficients for the fossil-fueled electric column vector in the refined oil and pipeline gas rows and decreasing the coefficient in the coal row. Changes in the energy product and nonenergy coefficients in the fossil electricity column are not required. Similarly, a shift in fuel mix for a specific energy product can be represented by altering coefficients in the A_{SP} submatrix.

Energy Sector Unit Measure Definitions

The incorporation of energy product sectors in the I-O allows quantitative representation of technological or other changes resulting in energy conservation within an industry. This can be accomplished by alteration of the coefficients depicting conversion of energy supplies to energy products, A_{SP} , the coefficient linking the energy product sectors to the nonenergy sectors, A_{PI} , and the energy product sectors to the energy supply sectors, A_{PS} , as represented in Table 2.

Turning to the 110×1 vector of GNP final demands, the values for each sector can be subdivided into 11 GNP purchasing components which will be discussed in the empirical estimation section. The vector of total

Table 2

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

i	j																			
	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	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
1.				RC PG	RC SO	RC ROP	RC PG	RC GE	RC GE				RC ORF	RC CF		RC PH		RC SH		
2.	CRL COG					ROP PG	ROP PG													
3.		SRL CSO				ROP														
4.							PG PG													
5.					SO ROP															
6.								ROP GF		ROP GF		ROP GF	ROP DG	ROP MP	ROP PH	ROP WH	ROP DG	ROP SH	ROP AC	
7.							GTL PG	DG GE		DG GE		DG CF	DG MP	DG PH	DG WH	DG SH	DG AC	DG EP		
8.								ETL GE		DE GE		DE MP	DE PH	DE WH	DE SH	DE AC	DE EP	DE EP		
9.									ETL GE	DE GE		DE MP	DE PH	DE WH	DE SH	DE AC	DE EP	DE EP		
10.										ETL GE	DE GE	DE MP	DE PH	DE WH	DE SH	DE AC	DE EP	DE EP		
11.											ETL GE	DE MP	DE PH	DE WH	DE SH	DE AC	DE EP	DE EP		
12.												*ETL GE	DE MP	DE PH	DE WH	DE SH	DE AC	DE EP	DE EP	

Final Demand
(Exports, Inventory Change, Imports)

Total Output

RC
CO
ROP
PG
GE
y_i

RC
COG
CSO
PG
SO
ROP
PG
GE
GE
GE
GE
GE
GE
x_i

I/O Coefficients $a_{ij} = T_{ij}/x_j$, where

are measured in units shown above.

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

Table 2 (cont'd.)

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

RC	-	Raw, extracted coal	PG	-	Processed pipeline quality gas
			GTL	-	Gas transmission loss
			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
RPO	-	Refined oil products	DE	-	Delivered electricity

1. crude oil and gas - oil refining loss - gas processing loss = refined oil products + processes, pipeline-quality gas

$$COG - CRL = ROP + PG$$

2. crude shale oil - shale oil refining loss = refined oil products

$$CSO - SRL = ROP$$

3. processed, pipeline-quality gas - dist/trans loss = delivered gas

$$PG - GTL = DG$$

4. generated electricity - dist/trans loss = delivered electricity

$$GE - ETL = DE$$

total sectoral output, X , is then calculated in the solution of the I-O, utilizing the following inversion:

$$X = (I-A)^{-1} Y.$$

Basic I-O Matrix Equations

The basic sectoral equations for the energy and nonenergy sectors are expressed as follows:

$$(1) \quad A_{SS} X_S + A_{SP} X_P + Y_S = X_S,$$

$$(2) \quad A_{PS} X_S + A_{PI} X_I + Y_P = X_P,$$

$$(3) \quad A_{IS} X_S + A_{II} X_I + Y_I = X_I.$$

These equations are important in the development of interface equations between the I-O and BESOM to be discussed in a later section.

C. Empirical Parameter Estimation

The empirical estimation of I-O parameters involves both exogenous and endogenous techniques. The exogenous estimation procedure is described here while the endogenous determination is described in the I-O/LP model linkage section.

Matrix Coefficient Determination

The determination of the A-matrix coefficients can be subdivided into two classes: those coefficients determined endogenously and those coefficients specified exogenously. As indicated earlier, the technical coefficients of the A_{SS} and A_{SP} submatrices are determined by functional relationships with the intermediate energy form flows, IEF's, from BESOM, either in the combined iterative mode or the reduced form mode.

The original CAC-BNL 101 sector I-O utilized A-matrix coefficients of production derived mainly from 1967 BEA I-O coefficients. The present 110 sector I-O utilizes nonenergy input coefficients estimated for 1985

based on numbers from the 1985 BLS 134-order transactions matrix. Additionally, five new supply technologies have been added to the I-O. The primary data source for the new energy technology supply coefficients is a report by Just of the MITRE Corp.⁹ This source provides detailed data on input requirements from the nonenergy sectors and on the Btu's required from energy supply sectors but provides minimal information on energy product requirements.

Introduction of New Technologies.

Introduction of a new energy technology into the I-O requires the specification of a fixed proportions production function, the calculation of a column vector of A_{PS} and A_{IS} coefficients on the basis of physical output in Btu's, and the addition of this column vector plus a blank row vector to the A matrix with provision for endogenous calculation of any necessary row coefficients.

Process cost data for new technologies is generally taken from detailed engineering cost studies; however, the estimates of the coefficients are based only on the specific plant scale characteristics considered. Inclusion of these new technology coefficients must be standardized to base year constant dollars for consistency.

As an example, given four energy supply/conversion sectors - coal, crude oil and gas, refined oil products, and pipeline gas - the nonenergy input coefficients for these sectors are derived from the BLS 1985 134-order transactions matrix. This matrix has been inflated from 1963 dollars to 1967 dollars, utilizing appropriate BLS deflators and then aggregated to conform with the BNL 110-sector system. The resulting coefficients in each column are then multiplied by the 1967 price of that

energy sector's output (1967 dollars per 10^6 Btu) to obtain coefficients in units of 1967 dollars per 10^6 Btu of energy output. Historical energy supply and energy product input coefficients for these sectors are derived from the CAC model for 1967 as described in ref. 12. The energy product coefficients have been projected to 1985 by using certain projections contained in the BNL Energy Sourcebook.⁵ Energy supply coefficients for 1985 are not projected because they are determined endogenously by combined solution of the I-O/LP system or the reduced form LP system. A-matrix coefficients for the 12 energy supply technologies for inputs from all BNL I-O sectors are presented in Appendix III.

The supply data base for the fossil electric, LWR electric, and hydroelectric technologies requires some modification prior to incorporation into the BNL I-O.¹² The methodology involved, disaggregation, normalization, aggregation, and conversion, is basic to much of the data base manipulations utilized in the BNL I-O coefficient determinations. This procedure applies to the non-energy sector inputs only.

The input coefficients for the energy product sectors are taken from ref. 11 and projected to 1985. Historical input coefficients for inputs from energy supply sectors are also taken directly from ref. 11 but not projected to 1985 because they are endogenously determined by the I-O/LP system solution.

The introduction of a new energy technology, coal gasification, into the I-O is briefly outlined. The high Btu coal gasification system coefficients are developed in the MITRE report.⁹ The only energy supply input to this sector is coal. In terms of energy product coefficients, refined

oil is the only energy input to this coal gas system. In this respect, the BNL I-O adopts the assumption that energy product use in the coal gasification sector is identical to that for refined petroleum except for chemical feedstocks and process heat requirements.

Nonenergy inputs to the coal gas sector are aggregated directly from MITRE coefficients. The nonenergy coefficients for the other energy supply technologies, taken from the MITRE report, are adjusted and aggregated for insertion into the I-O. The basic MITRE coefficients are utilized for the energy supply input coefficients, the energy product input coefficients, and the non-energy-input coefficients also.

The energy product coefficients in the I-O for 1985 and 2000 have been adjusted where energy use is expected to grow at a rate different from that in the sector's output. Present growth in energy use is lower than GNP growth.

D. Estimation of Final Demand

The final demand vector drives the BNL I-O model and, hence, represents a major component in the solution of an integrated I-O/LP system. The methodology employed by BNL to estimate final demands utilizes an aggregate GNP result determined by the DRI Long-Term Interindustry Transactions Model (LITM) in conjunction with BNL disaggregation procedures to insure consistency at the aggregate level.⁴ The BNL methodology relates all the detailed final demand estimates to a single GNP estimate so that as GNP forecasts change there will be corresponding changes in final demands.

The BNL methodology incorporates a four-stage procedure to estimate 1985 final demands.² Initially, the aggregate 1985 GNP is estimated.

Then it is divided into the following 11 purchasing components: personal consumption expenditures, gross private fixed domestic investment, changes in inventories, government defense expenditures, other federal government expenditures, state and local government education, state and local government health, state and local government safety, state and local government other, exports, and competitive imports.

Subsequently, each of these final demand components is divided into the 110 sectoral purchases and the purchases across all 11 GNP components are aggregated to obtain the GNP sector of final demand. Energy product final demands are not usually divided into more than two purchasing components (PCE and all government), however, since there is a lack of supporting data for further disaggregation.

In this "from the top down" procedure, forecasts of aggregate GNP are obtained from estimates utilizing variables such as: 1) future labor force; 2) future labor force productivity; and 3) future participation rates. This aggregate result is then disaggregated by GNP purchasing component (e.g., household, government, etc.) and by type of purchase (e.g., cars, clothes, etc.). This methodological approach insures feasible aggregate GNP estimates but does not insure disaggregated factor consistency. For example, labor and capital equipment required to produce aggregate GNP will be less than or equal to the amount available, whereas to meet the specific disaggregated final demands there may be shortages or surpluses of labor and/or capital. Likewise, aggregate GNP growth estimates do not insure homogeneity of individual sectoral growth rates, a very important bias in this type of estimation procedure.

After aggregate GNP parameters are estimated on the basis of aggregate feasibility conditions, feasibility in the disaggregate is then considered. If production of capital goods is not satisfied at the disaggregated level, the structure of the 1985 investment vector is adjusted until both aggregate and disaggregate feasibility conditions are satisfied. This capital investment adjustment routine will be described later.

The determination of the disaggregated final demands for 1985 in the BNL approach utilizes two major 1985 final forecasts of disaggregated final demands - those of Almon and of the BLS. Neither of these estimates has been adopted per se because of a range of variation between 1985 estimates of aggregated final demands and 1985 estimates of GNP. In this procedure, an estimate of the 1985 final demand is derived from these forecasts and then, via interpolation, estimates of final demands for the intervening years are obtained.

Table 3A indicates the general classification system utilized in developing the final demand estimates. The 1985 GNP in the lower right-hand corner of Table 3A is obtained from exogenous forecasts, and then the GNP is disaggregated into the column sums listed in the last row of Table 3A.* The purchase totals of the first seven columns exceed GNP by the amount of competitive imports, these being shown as negative entries. Competitive imports in this context refer to those kinds of imported goods and services which are also produced by domestic industries.

*For projection purposes, the four components of state and local government purchases are generally aggregated.

Table 3A

Aggregate GNP to Disaggregated Final Demands

Goods or Services Purchased	Type of Purchaser								
	Consumption	Fixed Investment	Inventory Change	Federal Gov't. Defense	Federal Gov't. Other	State and Local Gov't.	Exports	Competitive Imports (neg.)	Total Final Demand by Type of Product
Energy Supply Industries (Sectors 1-12) Crude Oil Coal Etc.									
Energy Products (Sectors 13-20) Space Heat Water Heat Etc.									
Nonenergy Industries (Sectors 21-110) Automobiles Shoes Airplane Travel Etc.									
Subtotal - Final Demand by Type of Purchaser	Y(.1)	Y(.2)	Y(.3)	Y(.4)	Y(.5)	Y(.6)	Y(.7)	Y(.8)	$Y = \sum_{i=1}^8 Y(.i)$
Purchases Excluded from Model Wage Income Non-Competitive Imports Rest of World									
Total - GNP by type of Purchaser	GNP(.1)	GNP(.2)	GNP(.3)	GNP(.4)	GNP(.5)	GNP(.6)	GNP(.7)	GNP(.8)	$GNP = \sum_{i=1}^8 GNP(.i)$

Table 3B
1967 I-O Prices

Sector	I-O Price (\$/10 ⁶ Btu, \$/S)	Total VA Purchases (1967 \$)	VA Coefficient (\$/10 ⁶ Btu, \$/S)
1	.180287	1.843801	.124544
2	.350076	8.825753	.220269
3	0.000000	0.000000	0.000000
4	0.000000	0.000000	0.000000
5	0.000000	0.000000	0.000000
6	.962923	4.291093	.184609
7	.609326	7.611699	.414697
8	0.000000	0.000000	0.000000
9	4.561563	11.376446	3.303633
10	4.581806	.062899	2.409903
11	0.000000	0.000000	0.000000
12	4.572238	3.079579	4.074703
13	.776133	0.000000	0.000000
14	.892776	0.000000	0.000000
15	4.814607	0.000000	0.000000
16	1.009560	0.000000	0.000000
17	1.731263	0.000000	0.000000
18	1.589040	0.000000	0.000000
19	1.660862	0.000000	0.000000
20	4.563629	0.000000	0.000000
21	1.004844	0.005600	.245829
22	.993274	13.953003	.496006
23	1.003950	.818800	.586263
24	1.000387	1.560600	.585571
25	1.029363	.513200	.461249
26	1.042975	.618201	.490965
27	.994719	1.323300	.552446
28	1.024297	.551000	.593670
29	1.012408	10.197398	.386485
30	1.011425	10.192208	.379062
31	1.006653	4.141097	.379256
32	.780253	3.807900	.454892
33	.994994	3.614101	.493325
34	1.008784	3.219800	.513968
35	1.001337	10.518593	.614020
36	1.007359	4.831203	.453320
37	1.003941	25.302664	.287877
38	1.000659	3.858602	.487437
39	1.019627	4.780100	.309640
40	1.009704	1.291001	.306008
41	1.006884	8.349296	.371070
42	1.010124	1.246001	.290980
43	1.001659	4.830408	.403990
44	1.001980	.218700	.405230
45	1.003804	2.263699	.441973
46	1.004848	1.273598	.456688
47	1.002235	5.802889	.379036
48	1.000941	2.179898	.361600
49	1.000997	10.919808	.494390
50	1.028203	8.614096	.383873
51	1.005916	2.598501	.314154
52	1.005178	4.852496	.390013
53	1.003420	1.004599	.344735
54	.994125	.144600	.243375
55	.991424	.128300	.220629
56	1.010881	6.375105	.469417
57	.990905	.325400	.322529
58	1.000595	1.830602	.433197
59	1.026570	2.116299	.575724
60	1.038878	5.028501	.464685
61	1.031702	13.022487	.432662
62	1.019632	5.934506	.317211
63	1.014990	1.141400	.340938
64	1.010853	4.593900	.369126
65	1.010707	4.143093	.452249
66	1.007424	5.493308	.451332
67	1.007369	1.370099	.366302
68	1.008470	1.688699	.371225
69	1.008297	2.513402	.427502
70	1.005181	.996700	.396563
71	1.001471	4.374279	.523812
72	1.002137	2.403901	.444664
73	1.004629	3.443403	.454757
74	.995504	2.183299	.554541
75	1.003710	2.747603	.423489
76	1.006409	1.664199	.316129
77	1.004855	4.550901	.470070
78	1.008088	1.930598	.355031
79	1.006368	1.916700	.474038
80	1.003217	7.789905	.470733
81	1.006833	3.682298	.461954
82	1.008791	1.293100	.427002
83	1.009004	13.551500	.314343
84	1.002654	9.485209	.434688
85	1.007201	2.874596	.377311
86	1.001209	2.613397	.435063
87	1.004380	2.678702	.588118
88	1.001623	3.932499	.452227
89	1.017705	8.152203	.641868
90	1.005891	3.409005	.622677
91	.979454	11.219790	.612540
92	1.018912	1.548797	.325907
93	1.018314	4.554902	.572057
94	.974148	.806101	.464253
95	1.000477	.848900	.833808
96	1.000361	16.161612	.836577
97	.999483	1.580400	.496454
98	1.018263	.839700	.235654
99	1.000489	117.368161	.724270
100	1.002666	26.976196	.566797
101	.993392	84.072781	.742426
102	1.015169	12.405996	.596308
103	1.002657	29.082093	.515981
104	1.001584	8.138808	.551911
105	.998808	5.088097	.527599
106	.998692	33.899897	.698920
107	.999924	5.497802	.769373
108	1.007972	3.430502	.544425
109	1.009650	0.000000	0.000000
110	1.003732	0.000000	0.000000

PRICE INDEX= 1.00264

Each column sum is then disaggregated into two components, those purchases included in the eventual final demands which drive the BNL I-O model, and "other purchases." These other purchases are primarily purchases of noncompetitive imports, purchase of goods produced by U.S. firms located out of the U.S., and direct purchases of labor services by households and government. Initially the percentage splits between included and excluded purchases are estimated and then they are used to obtain the subtotals listed as Y(.1) through Y(.8) in Table 3A.

Initially, energy final demands are estimated in Btu's, converted to 1967 dollars, and then the residuals for other interindustry purchases are estimated. A list of historical 1967 energy prices used for conversion of Btu's to 1967 dollars is presented in Table 3B. The column totals from Table 3A are then disaggregated into purchases from each individual industry utilizing the ratios derived from the analysis of the 1985 final demands estimated from BLS and Almon demands.

Since final demand drives the BNL I-O, estimates of the GNP are critical to the model solution. Presently an estimated value for GNP and an annual growth rate are obtained from the DRI LITM.³ Earlier forecasts utilized a survey of GNP estimates. Depending on the assumptions deemed plausible, a range of GNP estimates can be obtained.

The estimation of the percentage distribution of GNP by type of purchaser is an important component in the development of the I-O sectoral composition. Historical GNP component breakdown has indicated relative long-run stability in the share of gross private domestic fixed investment despite a long-run shift in income shares toward a greater share of personal disposable income and a smaller share of corporate retained

earnings. Additionally, higher personal savings have somewhat offset declining corporate savings as a source of investment funds. Most forecasts suggest an even smaller change in real output shares in GNP between the present and 1985.²

The BNL estimate of real output shares has been obtained by extending 1974 to 1983 National Planning Association estimated trends to 1985.² The output share of personal consumption expenditures in GNP is expected to stay relatively constant over time. The share of gross private domestic fixed investment is expected to increase as a result of the capital investment required to expand domestic production of energy in response to high current levels of energy imports and energy prices. The consistency between these investment estimates and the I-O capital routine estimates is obtained by iteration when necessary.

Further disaggregation of the government nondefense expenditure category and the net exports category has been detailed for the BNL model. Specifically, government nondefense expenditure has been split into federal-other and state and local government expenditures. National Planning Association estimates for the government nondefense expenditures are utilized for this category. Net exports have been split into gross exports and negative entries for competitive imports.

The shares of both gross exports and competitive imports in GNP have been increasing at an increasing rate. The share of competitive imports is then estimated as a residual given the estimates of net imports and gross exports. Conversion to appropriate constant dollar values is then performed. Similar computations for the years between 1977 and 1985 are

then made. The expenditure column totals then become GNP totals, by type of purchaser.

Table 4 provides an earlier version of the expenditure category estimation procedure. In the estimation of excluded purchases by type of purchaser, there are several types of purchases which are included in GNP estimates but are excluded from estimates of final demands for goods and services used in the I-O model. The major component of these excluded purchases refers to wage payments for government employees.

The other major categories of purchases excluded from I-O final demands are overseas U.S. transactions and "noncompetitive" imports and secondhand product transactions. Adjusting for U.S. "outside" transactions puts all I-O final demands on a domestic output basis rather than a national output basis, i.e., territorial U.S. final demand. The area of "noncompetitive" imports refers to imports without significant domestic counterparts or conversion prior to final sale. Projections for noncompetitive imports and U.S. "outside" transactions are derived by trend extrapolation as are secondhand product transactions. Computation of total exclusions by type of purchases is accomplished by multiplying the ratios between excluded purchases and total purchases, for given years, by the estimated total purchases for a given purchase category.

The next step is the estimation of 1985 final demand sectoral shares by type of purchaser. This involves the disaggregation of the final demand total purchases, $Y(.1) - Y(.8)$, into different interindustry purchase categories, sectors 1 to 12 for energy fuel demand purchases, and

Table 4

Derivation of Estimated 1974-1985 GNP in 1958 and 1967 Dollars
By Six GNP Expenditure Categories

	GNP (Billions of 1958 \$)	GNP Share (Percent)	Amount (Billions of 1958 \$)	1967/1958 Price	Amount (Billions of 1967 \$)
<u>Personal Consumption Expenditures</u>					
1974	\$ 821.6	66.5%	\$546.4	1.144	\$625.1
1975	805.2	67.2	541.1	↓	619.0
1976	861.6	66.2	570.4		652.5
1977	913.3	66.4	606.4		693.7
1978	959.0	66.3	635.8		727.4
1979	993.3	66.4	659.6		754.5
1980	1027.6	66.5	683.4		781.8
1985	1220.4	66.8	815.2		932.6
<u>Gross Private Fixed Capital Formation</u>					
1974	\$ 821.6	14.3%	\$117.5	1.159	\$136.2
1975	805.2	13.9	111.9	↓	129.7
1976	861.6	14.8	127.5		147.8
1977	913.3	15.3	139.7		161.9
1978	959.0	15.7	150.6		174.5
1979	993.3	15.7	155.9		180.7
1980	1027.6	15.7	161.3		187.0
1985	1220.4	15.3	186.8		216.5
<u>Government Nondefense</u>					
1974	\$ 821.6	13.0%	\$106.8	1.365	\$145.8
1975	805.2	13.0	104.7	↓	142.9
1976	861.6	13.4	115.5		157.7
1977	913.3	12.7	116.0		158.3
1978	959.0	12.4	118.9		162.3
1979	993.3	12.4	123.2		168.1
1980	1027.6	12.4	127.4		173.9
1985	1220.4	12.8	158.2		213.2
<u>Government Defense</u>					
1974	\$ 821.6	4.7%	\$ 38.6	1.216	\$ 46.9
1975	805.2	4.5	36.2	↓	44.0
1976	861.6	4.3	37.0		45.0
1977	913.3	4.2	38.4		46.7
1978	959.0	4.0	38.3		46.6
1979	993.3	3.9	38.7		47.1
1980	1027.6	3.9	40.1		48.8
1985	1220.4	3.6	43.9		53.4

Table 4 (continued)

	GNP (Billions of 1958 \$)	GNP Share (Percent)	Amount (Billions of 1958 \$)	1967/1958 Price	Amount (Billions of 1967 \$)
<hr/>					
Net Inventory Change					
1974	\$ 821.6	0.6%	\$ 4.9	1.176	\$ 5.8
1975	805.2	1.3	10.5	↓	12.3
1976	861.6	1.0	8.6		10.1
1977	913.3	0.9	8.2		9.6
1978	959.0	0.8	7.7		9.1
1979	993.3	0.8	7.9		9.3
1980	1027.6	0.8	8.2		9.6
1985	1220.4	0.9	11.0		12.9
<hr/>					
Net Exports					
1974	\$ 821.6	0.9%	\$ 7.4	1.444	\$ 10.7
1975	805.2	0.1	0.8	↓	1.2
1976	861.6	0.3	2.6		3.8
1977	913.3	0.5	4.6		6.6
1978	959.0	0.8	7.7		11.1
1979	993.3	0.8	7.9		11.5
1980	1027.6	0.7	7.2		10.4
1985	1220.4	0.6	7.3		10.5

Sources:

Column (1): BNL estimates. The methodology used to derive the 1980 and 1985 estimates is explained in Ref. 2. The 1975-1978 estimates were derived on the assumption that real GNP will grow at the following rates: 1975, -2%; 1976, +7%; 1977, +6%; 1978, +5%.

Column (2): 1980 and 1985 estimates are linear extrapolations of N.P.A. estimates for 1973-1978-1983. The U.S. Economy: 1973 to 1983, National Planning Association Report Number 73-N-1, Table II-7.

Column (3): Column (1) times Column (2)

100

Column (4): Survey of Current Business, Department of Commerce. The government defense inflator is for all federal government purchases. The government non-defense inflator is for state and local government purchases; the net inventory change inflator is the aggregate GNP inflator.

Column (5): Column (3) times Column (4).

sectors 21 to 110 for nonenergy final demand purchases.* The general sources of data utilized are: 1) historical BEA I-O final demands for 1963 and 1967; 2) Almon's 1985 final demand forecasts; and 3) BLS's 1985 final demand forecast.² Both of the final demand forecasts are converted to the BNL 110 order I-O in 1967 dollars.

For each sector, first the Almon and BLS estimates are converted to "final demand coefficients" by dividing each industry entry by the total of all included entries for each expenditure category. Hence, a coefficient, f_{ij} , equals the 1967 dollars worth of i per 1967 dollars worth of all products purchased by expenditure category j , and

$$\sum_{i=1}^{110} f_{ij} = 1$$

for $j = 1, 8$.

In most cases a weighted average of the Almon and BLS coefficients has been used to estimate the BNL 1985 coefficients.² In the process of integrating BLS and Almon estimates, some sector realignment and price deflation have been necessary to achieve consistency between these two estimates.

Differences in the BLS and Almon estimates are due to basic convention variations, aggregate income estimate differentials, and different forecasting methodologies. The case of personal consumption expenditures, PCE, illustrates the forecasting differences. Specifically, the values of the categories included in the PCE national income accounts

* For PCE and government components, estimates for sectors 1 to 12 are reallocated to sectors 13-20; i.e., in terms of end-use demands instead of fuels.

can be forecasted directly, and then these values converted into the I-O industry classification system by use of a bridge table between PCE and I-O final demand categories. Alternatively, the I-O final demand categories can be forecasted directly. Reference 2 provides a comparison of the Almon and BLS 1985 coefficients and a comparison of the 1985 BNL coefficients with corresponding 1967 BEA coefficients.

A summary of these comparisons indicates stability of the relative share components for the aggregate estimates at the 110-order level. Significant changes, however, are evidenced by increases in the purchases of electricity and other transportation equipment, and decreases in the share of for-hire passenger transportation excluding rail and air. It should be noted that these comparisons are for the 1985 PCE sectoral share estimates of BNL and the 1967 BEA values. A sectoral share estimate is calculated utilizing the following expression: dollars of category purchased/dollars of total expenditure category (e.g., PCE).

Gross private fixed capital formation, GPFCE, sectoral share estimates are computed in the same fashion as the PCE estimates. In terms of the aggregate classification system, minimal change is estimated to occur between 1967 and 1985 -- the largest change being a slight decrease in the share of construction.

The estimation of 1967 to 1985 sectoral shares incorporates linear interpolation of the 1967 and 1985 Y_{ij} coefficients. Specifically, for any year $1967 + t$, where $0 < t < 18$, the following relationship holds:

$$(1) \quad Y_{ij}^{67+t} = (t/18) Y_{ij}^{85} + (18-t/18) Y_{ij}^{67},$$

where

Y_{ij} = dollars worth of sector i output purchased by final demand sector j per dollars worth of total included expenditures by final demand sector j.

The estimation of the 110-order final demand vector in constant 1967 dollars involves aggregation of the sectoral components and multiplication by respective share coefficients. Specifically, the 110 x 1 final demand vector for any year, 1967 + t, for sectors 1 to 12 and 21 to 110 is obtained by multiplying the f_{ij}^{1967+t} share coefficient by each column sum, F_j^{1967+t} , and adding across all final demand categories (eight or eleven depending on the degree of disaggregation). That is:

$$(2) \quad Y_i^{67+t} = \sum_{j=1}^8 f_{ij}^{67+t} F_j^{67+t} \text{ for all } i, i = 1, 12; 21, 110$$

$$Y_i = 0 \text{ for all } i = 13, 20.$$

where

Y_i^{67+t} is the final demand for output of sector i in year 1967 + t,

f_{ij}^{67+t} is the dollar's worth of i purchased per dollar's worth of final demand category j total purchases for 1967 + t,

and

F_j^{67+t} is the dollar's worth of purchases of included goods and services for 1967 + t from the 1967 and 1985 values derived from Table 3 data in constant 1967 dollars.

The determination of final demands for energy sectors 1 to 20 involves several steps. As noted earlier, all energy requirements in the

BNL I-O are expressed in terms of Btu's rather than dollars. The three final demand purchase categories, inventory change, gross exports, and competitive imports are defined in Btu of energy fuels, consistent with Table 2, and entered in sector rows 1 to 12. These final demands for 1985 are estimated as follows.

Sectoral shares for the five BEA energy sectors (coal, crude oil and gas, refined oil, gas utilities, and electric utilities) are estimated with reference to Almon and BLS forecasts in the same manner as the nonenergy sectors. The sectoral energy shares, dollars of Category purchased/dollars of total expenditure category, are applied to the 1985 "total purchases" estimates for the three final demand sectors to obtain 1985 final demand energy estimates in 1967 dollars. The 1985 final demand dollar values are then compared with the corresponding 1967 BEA final demand values. Finally, the 1985 to 1967 ratios of dollar values are applied to 1967 Btu values for energy supply final demands from ref. 10 to obtain 1985 Btu final demands for energy supplies for the specific categories of inventory change, exports, and imports.

Because fuels and electricity are not durable goods, there are no entries from sectors 1 to 12 for the GNP components, GPFCE. The final demands for energy for the remaining final demand sectors (PCE and government) are defined in terms of the eight energy product sectors in the I-O because they represent final energy consumption. For each of the final demand categories, the basic approach utilized in the estimation of Btu product requirements first involves the determination of the expected change in the requirement from 1967 to 1985 for each product. These per-

cent changes are then applied to total 1967 Btu final demands from these same energy product sectors from ref. 10 to yield an estimate of 1985 Btu demands.

Table 5 presents the 1985 version of Btu final demands for the 110-order model under the assumption of high energy prices. It should be noted that the unit of measurement for sectors 1 to 20 is in units of 10^{15} Btu while the unit for sectors 21 to 110 is 1967dollars. A comparison of the 1985 BNL final demands with the 1967 BEA final demands indicates that changes in final demand for sectors exhibiting significant increase tend to result from increased export rates and increased sales to other businesses on capital account. Other sectors exhibiting increase apparently are responding to substantial increases in consumer demand. For those sectors exhibiting significant final demand decrease from 1967 to 1985, a major factor appears to be either increased imports and/or decreased exports.

As indicated earlier, the final demands for energy products are expressed in Btu's of product units measured at the point of end-use. It is interesting to note that I-O space heat demands account for approximately 50% of all final demands for energy product Btu's and motive power for approximately 25% of the total. Of the various GNP components, PCE accounts for about 80% of all energy product final demands with the remainder being government demand.

E. Evaluation of Basic I-O Model

An important consideration in the I-O format is the constraint implicit in the model's fixed input-output coefficient structure. The basic structure of the fixed coefficient methodology precludes production

Table 5

I-O/LP Final Demands
 1985 High Energy Price - III
 Sectors 1-20 in 10¹⁵ Btu
 21-110 in 10⁹ 1967 \$

1. 2.52478	29. 43.08847	57. -.12836	85. 13.73087
2. -4.28399	30. 59.61102	58. 2.61215	86. .4.28406
3. 0.00000	31. 31.47358	59. .46367	87. 4.54178
4. 0.00000	32. 6.39321	60. .53889	88. 9.79037
5. 0.00000	33. 8.98044	61. -1.98771	89. 7.31305
6. -.00096	34. -7.49838	62. -.72171	90. 4.13437
7. -2.11559	35. 18.10595	63. .03833	91. 10.48251
8. 0.00000	36. 5.42178	64. 4.08885	92. 2.89166
9. -.00907	37. 99.11171	65. .76243	93. 7.47498
10. 0.00000	38. 7.34102	66. 3.12838	94. .18960
11. 0.00000	39. .79009	67. 4.48880	95. .87667
12. 0.00000	40. 2.27166	68. 3.32456	96. 24.10611
13. 0.00000	41. 25.58771	69. 6.27564	97. .17383
14. .15100	42. 4.07352	70. 2.87794	98. 2.36820
15. 3.34800	43. .24844	71. 4.05019	99. 225.74021
16. .57300	44. .00072	72. 6.11711	100. 49.31210
17. 1.20200	45. 6.42818	73. .4.05898	101. 145.45878
18. 4.34100	46. 3.61436	74. . .36334	102. 26.60510
19. 1.67600	47. 3.55920	75. 10.70928	103. 15.28811
20. 1.59000	48. .52067	76. 5.73487	104. 12.66309
21. 3.43975	49. 9.34700	77. 6.57321	105. 8.86247
22. 9.99193	50. 6.35553	78. 8.55330	106. 95.97720
23. -.30443	51. 1.82785	79. 1.95738	107. 4.58691
24. .03938	52. 22.07393	80. 17.83074	108. 2.60054
25. -.74411	53. .19324	81. 2.57110	109. -.75095
26. -.32786	54. .01134	82. 1.69467	110. 1.26957
27. .01398	55. .00711	83. 53.53189	
28. -.33188	56. 6.86977	84. 11.53264	

processes from exhibiting any input substitution possibilities, given variation in relative input prices. Since long-run price variation is an economic reality, the general equilibrium results of the I-O are necessarily biased. The assumption of constant returns to scale can also add a bias to these results.

Implicit in the structure of the fixed coefficient model is the lack of price-sensitive demand response. Given this weakness, however, the main purpose of the fixed coefficient I-O is to provide a consistent method of accounting for interindustry energy and material flows in addition to other economic factors. The strength of the fixed coefficient I-O is its ability to elicit structural changes resulting from changes in the composition of final and/or intermediate demands. The conventional static I-O, however, contains no explicit theory of investment, hence, consistency in the supply and demand of capital goods for the projected year is lacking.

III. DYNAMIC EXTENSION OF THE I-O: THE CAPITAL INVESTMENT SUBROUTINE

A. Introduction

The basic static version of the I-O model does not consider intertemporal capital adjustment mechanisms since it already assumes sectoral equilibrium. In reality, the capital investment structure is a major factor in the stability of a general equilibrium model. In the static structure there is no guarantee of consistency between the capital investment required and the capital investment supplied in the model for the year being modeled. This is overcome by estimating capital investment demand as a function of current and historical sectoral I-O outputs, capital coefficients, and a capital replacement vector. This yields an

estimate of the capital requirement necessary to support the indicated growth in output from the base year. Capital supply as specified by the GPFCF component of GNP can thus be checked with the estimate of capital demand and adjusted accordingly. Investment is modeled in a dynamic sense by a simple accelerator model.

The purchase category of Gross Private Fixed Capital Formation, GPFCF, is estimated at the 110 sector level of detail, but there is no guarantee that this estimate is consistent with a general equilibrium solution. The accuracy of this initial forecast can be checked with the aid of a capital/output coefficient matrix. This capital coefficient matrix is composed of a column vector of coefficients for each sector which describes all capital purchase required to support a unit expansion in output. Utilizing this matrix, one can determine if the capital formation estimate is sufficient to support the increase in sectoral levels of production relative to those of a base year plus the replacement of worn out capacity.

Capital Investment Assumptions

In the accelerator model it is assumed that all outputs grow at steady-state rates from the same historical year, that capital coefficients remain constant over that time span, and that replacement rates for worn-out stock remain constant over that time span.

B. Capital Investment Model

The level of investment, I , represents an estimate of the amount of capital required either to replace depreciated capital equipment or to increment existing capital stock. Independent estimation of annual capital demand utilizes capital coefficients.

By definition, the gross annual investment demand of sector j , I_j , for the period 1984-85 can be expressed as

$$(1) \quad I_{0j}^{84-85} = \sum_i K_{i,j}^{85} - K_{i,j}^{84} + \delta_j K_j^{84},$$

where

K_{ij} = type- i capital required for sector j production,

δ_j = capital replacement rate for sector j .

A steady-state growth rate of output, g_j , for each sector is assumed over the 1967-1985 time span, yielding

$$(2) \quad g_j = (1/18) \ln (X_j^{85}/X_j^{67})$$

Given the average growth rate over this time period, the annual capital investment requirement can be determined according to the accelerator theory of capital investment. The total 1985 capital requirement of sector j for sector i 's capital output, $I_{D_{i,j}}$, is specified as:

$$(3) \quad I_{D_{i,j}}^{1985} = CAP_{i,j} \times X_j^{1985} \times \left(1 - \frac{1-\delta_j}{1+g_j} \right),$$

where

$CAP_{i,j}$ = capital coefficient of sector j 's capital requirement

from capital supplying sector i , $= \frac{K_{ij}}{X_j}$

X_j^{1985} = 1985 total output of sector j ,

δ_j = capital replacement rate for sector j ,

g_j = average annual growth rate of total output of sector j .

The total annual capital requirement for sector j is obtained by summing over all i capital coefficients in column j; i.e.,

$$(4) \quad I_{D_j}^{1985} = \sum_i I_{D_{i,j}} = \sum_i CAP_{i,j} \times X_j \times \left(1 - \frac{1-\delta_j}{1+g_j} \right)$$

Summation over all j demand sectors, i.e.,

$$(5) \quad I_D = \sum_j I_{D_j}$$

yields the total annual equilibrium capital investment requirements for all 110 I-O sectors, excluding new residential construction capital requirements.

Analogously, the same development is utilized to determine the equivalent capital investment requirements in terms of supplying sector i, by summing over all j columns; i.e.,

$$(6) \quad I_{S_i}^{1985} = \sum_j CAP_{i,j} \times X_j \times \left(1 - \frac{1-\delta_j}{1+g_j} \right)$$

Summation over all i rows yields total capital by supplying sector exclusive of new residential construction; i.e.,

$$(7) \quad I'_S = \sum_i I_{S_i}$$

where (7) = (5). The exogenous specification of the new residential construction component of GPFCF, $Y_{(29,2)}$, must be added to either (5) or (7) to determine total capital requirements. Hence, the equilibrium total for investment requirements by supplying sector is written as

$$(8) \quad I_S = \sum_{i=1}^{28} I_{S_i} + \sum_{i=30}^{110} I_{S_i} + Y_{(29,2)}$$

The adjustment mechanism replaces the original $Y_{(i,2)}$ vector with the equilibrium capital supply vector I_{S_i} where $I_{S_{29}} = Y_{(29,2)}$. In this adjustment process GNP is assumed to remain constant, and the compensatory adjustment for altering the GPFCE vector is made to the initial PCE vector $Y_{(i,1)}_0$ for $i = 21, 110$. PCE is adjusted according to the formula

$$(9) \quad Y_{(i,1)} = \frac{\sum_{i=1}^{110} Y_{(i,2)} - I_{S_i}}{\sum_{i=21}^{110} Y_{(i,1)}_0} \times Y_{(i,1)}_0 + Y_{(i,1)}_0$$

IV. INPUT-OUTPUT CAPITAL COEFFICIENTS FOR ENERGY SECTORS 1 TO 12

A. Introduction

Input-output capital coefficients measure the purchase of durable goods and structures that are necessary to expand productive capacity. The coefficients are defined in terms of 1967 dollar purchases/ 10^6 Btu output from new capacity.

The basic capital coefficient matrix used in the BNL model was developed at Battelle by Fischer and Chilton.⁷ Conversion of the Battelle coefficients to 1967 dollars permits introduction into the BNL model. The column coefficients for nonenergy sectors are expressed in terms of 1967dollars/1967dollars. In the energy sectors, the BNL model expresses sector output in terms of Btu's, hence, the capital coefficients are converted to units of 1967 dollars/ 10^6 Btu.¹² The Battelle coefficients are used for the four energy sectors: coal, crude oil and gas, refined oil products, and pipeline gas. It should be noted that all capital purchases are from nonenergy sectors, hence, the numerators of all coefficients are always measured in dollar terms in the BNL model.

Coefficients developed by MITRE are used for the three nonelectric energy sectors: shale oil, methane from coal, and syncrude. Coefficients are estimated from pilot plant and technical sources and expressed in terms of 1967dollars/ 10^6 Btu. Specific adjustments are made whenever feasible to reflect a different plant operating factor or different output definition.¹⁴

These three nonelectric sectors are different from all other I-O sectors in that no administrative or management functions are included. The coefficients for these sectors are defined solely on the basis of a technological process. The BNL model adjusts for all overhead functions by having these specific sectors sell all their output to traditionally defined I-O sectors; i.e., pipeline gas or refined oil products.

The five electric sectors in the BNL model are in part based on the work of Istvan.⁸ Istvan has disaggregated the conventional electric utility sector into seven "processes": fossil, hydroelectric, nuclear, electrical peaking facilities, electrical transmission facilities, electrical distribution, and administrative overhead. Istvan's capital coefficients for the last three processes, transmission, distribution, and administration, are applied to all five BNL electric sectors.⁸

B. Capital Coefficients for Nonelectric Energy Sectors

Estimates of Fisher and Chilton⁷ are used for four nonelectric energy sectors -- coal, crude oil and gas, refined oil products, and pipeline gas. After adjustment to 1967 dollars, they are normalized to a Btu output basis by multiplication by implicit I-O prices for each fuel.¹⁵ A representative set of capital coefficients is presented in Table 6, with

Table 6

Capital Coefficients for Non-Electric
Energy Sectors, 1967 \$/10⁶Btu

BNL Sector	Shale Oil	Methane From Coal	Solvent Refd. Coal	Coal	Crude Oil & Gas	Refined Oil Prds.	Pipeline Gas
27	.001838						
30	4.305273	4.704733	5.128309	.023712	.006907	.577212	.043176
31	.085740					.002282	1.406063
33	.021300			.007006	.465705		
40	.000010			.000076	.000024		.000049
43	.000001			.000007	.000002	.000741	.000005
45	.000012			.000120	.000038		.000075
46	.000272			.002855	.000900	.000240	.001803
50	.055673	.015076	.012173				
56	.002347			.001313	.000507		.003650
58	.000001			.000025	.000008		.000016
60	.036290	.002104	.016012			.002095	
63					.000019	.000179	
64	.264997	.447364	.109076	.016867	.006517	.029584	.046880
66	.165520	.121554	.067166	.001792	.004181	.008514	.016133
67	.057581	.052683	.028483	.004879	.005313	.002968	.010609
69	.063882	.026738	.007405	.083078	.029948	.000046	.037054
70	.049447	.015144	.017430	.009987	.003859	.006709	.027758
71	.000365	.000891		.001755	.000235	.000838	.005889
72	.000498	.000934		.001403	.001674	.062861	.006160
73	.114140	.150118	.130038	.011822	.004568	.045281	.034522
75	.002973			.002064	.006490	.011100	.011139
76	.004393	.022117		.004198	.002908	.004118	.006914
77	.081003	.058900	.009482	.003738	.004712	.016504	.123694
79	.018753	.003332	.057100	.000076	.000096	.000234	.002515
80	.001866				.000903	.000790	.000552
81					.000012		
82	.000477			.000148	.000186	.000481	.004890
83	.012202			.029431	.001359	.012557	.003925
84	.009865				.000704		.000077
85	.000217			.017933	.001772	.000056	.001203
86	.020868	.013854	.034216	.001118	.001287	.020350	.025179
87	.000099			.000848	.000269	.002072	.001872
88	.004454			.006089	.002353		.016924
89	.008058	.007393	.003759	.001472	.001277	.006261	.003220
91	.011232	.010700	.005441	.001549	.001478	.015582	.006118
92	.000408	.000389	.000198	.000026	.000026	.000093	.000079
93	.000996	.000973	.000495	.000013	.000011	.000241	.000068
95	.000011			.000017	.000018	.000464	.000227
99	.076390	.065684	.043396	.016355	.010908	.003944	.048666
100			.008102				
101		.000281					
103		.002021	.044700				
Total (K/O Ratio)	5.479452	5.722983	5.722983	.251772	.567173	.834397	1.897104
Assumed Plant Factor	90%	90%	90%	--	--	--	--

the sum of the coefficients in each column equaling the K/O ratio for that sector.

C. Capital Coefficients for Electric Sectors

Since Istvan does not explicitly develop K/O ratios for his seven process vectors, appropriate ratios must be calculated from the breakdown of capital expenditures by process as indicated in Table 7. Investment in the four types of power production is estimated first using the capital cost and capacity increment estimates of Istvan. This represents a given percentage of the capital investment. Allocation of this total to transmission, distribution, and administrative overhead follows from Istvan's proportionality split in the first column of Table 7. Capital coefficients for the seven processes can now be calculated using proportional breakdowns presented in Table 6, the K/O ratios in Table 7, and the value added coefficients reassigned to BNL sector 31. The transmission, distribution, and administrative overhead coefficients are added to form a general overhead vector. Table 8 lists the capital process coefficients for electric utilities. Table 9 presents the addition to the capital coefficient for sector 31 that is made in order for the sum of the capital coefficients to equal Bechtel's K/O ratio for each electric generation vector ref. 1. Table 10 presents the final capital coefficients and K/O ratios for the five electric sectors. The transmission, distribution, and administrative coefficients in Table 8 have been added to each of the five electric generation vectors in that table. The coefficients for sector 31 have been adjusted upward by the amounts shown in Table 9.

Table 7

Capital/Output Ratios for
Istvan's Electric Process Vectors

Type	Proportion of Total Investment	Capital Cost, * 1967 \$/kw	1980 Capacity Addition, 10 ⁶ kw	Investment, 10 ⁹ 1967 \$	Annual Output, 10 ¹⁵ Btu	K/O Ratio, 1967 \$/10 ⁶ Btu
Power Production	.4905					
fossil		155.1	15.0	2.3265	.2466	9.4349
nuclear		216.2	25.0	5.4050	.4110	13.1517
hydro		244.4	5.7	1.3931	.0937	14.8671
peaking		84.6	2.6	.2200	.0078	28.3046
Transmission	.1997			3.8045	.7590	5.0123
Distribution	.2767			5.2714	.7590	6.9449
Administration	<u>.0331</u>			<u>.6306</u>	.7590	.8308
Total	1.0000			19.0511		

*Istvan's estimates (1968 \$) deflated by the Handy-Whitman public utility, electric light & power price index, 0.94.

Table 8

Capital Process Coefficients
for Electric Utilities, 1967 \$/10⁶ Btu

BNL Sector	Tran, Distr & Admin	Fossil & Peaking	Hydro- Electric	LWR Electric	HTGR Electric	Coal CMBND Cycle
22				.000092	.000093	
24				.000093	.000148	
27				.000560	.000962	
31	7.765640	3.404496	11.478277	2.543670	3.903821	.941163
33						.192688
36				.001537		
39					.000053	
40	.004054				.000032	
43	.381481			.003264	.005343	
45	.001321					
46	.026366	.002084	.202296	.016179	.003352	.000852
47	.020981			.000087	.000295	
50				1.494481	1.717671	
51					.000678	
53				.001632	.003215	
54				.000563	.000760	
56				.000821	.001677	
59				.000071	.000120	
60	.059003			.031692	.530695	.130653
61	.079971			.021471	.383504	
62	.716407			.061320	.220254	.017716
64	.283799	2.190443		1.107020	.611117	.537947
65				.000135	.000215	
66	.031155	.678674	.025720	.611660	.763196	.195639
67	.002634	2.943766	2.478104	.816298	.798429	.911179
69	.026032			.000065	.000107	.004950
70	.008101	.036887	.154811	.035711	.191783	.014576
71	.016725	.012132				.001808
72				.203469	.216982	
73	.009535	.550865	.064746	.981144	.964510	.148473
74	.000842			.000058	.000096	
75	.008913			.084106	.135802	.012512
76	.002915				.038372	
77	1.931094	1.526798	.146634	.561906	.835912	.601688
78					.000055	
79	.420781	.083584	.009887	.125244	.054604	.142167
80	.224776	.003039		.000871	.002533	.001911
81	.001279				.011919	
82	.011968			.000707	.000122	
83	.099127					
84	.006969					
86	.006924			.121178	.215528	.025711
88				.000531	.000793	.000672
89	.117454	.164273	.053313	.032298	.053276	.015795
91	.168993	.237764	.077175	.046747	.091947	.022861
92	.006144	.008644	.002810	.001700	.002903	.000831
93	.015361	.021618	.007017	.004250	.006880	.002078
96				.000493	.000791	
99	.136579	.114232	.038773	.341104	.477201	.148305
100				.000714	.001124	.106053
101	.012441	.001378	.091388	.851876	.001382	
103	.183118	.039322	.036127	.002103	.003559	.487674
104				.000535	.000889	
106				.000115	.000179	
107				.000040	.000068	
108				.000042	.000065	
109				.000834	.001301	
110				.000426	.000066	

Table 9

Adjustment to Electric Generation Vectors, 1967 $\$/10^6$ Btu

	<u>Bechtel K/O Ratio</u>	<u>Sum of Just or Istvan Coefficients</u>	<u>Adjustment to Sector 31 Purchases</u>
fossil electric	14.2302	12.0201	2.2101
LWR electric	17.7930	10.1109	7.6821
HTGR electric	17.7930	12.2564	5.5366
Coal Combined Cycle	26.4798	4.6659	21.8139

Table 10

Capital Coefficients for Electric Sectors,
1967 \$/10⁶Btu Generated Electricity

<u>BNL Sector</u>	<u>Fossil Electric</u>	<u>Hydro- Electric</u>	<u>LWR Electric</u>	<u>HTGR Electric</u>	<u>Coal CMBND Cycle</u>
22			.000092	.000093	
24			.000093	.000148	
27			.000560	.000962	
31	13.380265	19.243917	17.991453	17.206135	30.520687
33					.192688
36			.001537		
39				.000053	
40	.004054	.004054	.004054	.004086	.004054
43	.381481	.381481	.384745	.386824	.381481
45	.001321	.001321	.001321	.001321	.003121
46	.028450	.228662	.042545	.029718	.027218
47	.020981	.020981	.021068	.021276	.020981
50			1.494481	1.717671	
51				.000678	
53			.001632	.003215	
54			.000563	.000760	
56			.000821	.001677	
59			.000071	.000120	
60	.059003	.059003	.090695	.589698	.189698
61	.079971	.079971	.101442	.463475	.079971
62	.716407	.716407	.777727	.936661	.734123
64	2.474242	.283799	1.390819	.894916	.821746
65			.000135	.000215	
66	.709829	.056875	.642815	.794351	.226794
67	2.946400	2.480738	.818932	.801063	.913813
69	.026032	.026032	.026097	.026139	.030982
70	.044988	.162912	.043812	.199884	.022677
71	.028857	.016725	.016725	.016725	.018533
72			.203469	.216982	
73	.560400	.074281	.990679	.974045	.158008
74	.000842	.000842	.000900	.000938	.000842
75	.008913	.008913	.093019	.144715	.021425
76	.002915	.002915	.002915	.041287	.002915
77	3.457892	2.077728	2.493000	2.767006	2.532782
78				.000055	
79	.504365	.430668	.546025	.475385	.562948
80	.227815	.224776	.225647	.227309	.226687
81	.001279	.001279	.001279	.013198	.001279
82	.011968	.011968	.012675	.012090	.011968
83	.099127	.099127	.099127	.099127	.099127
84	.006969	.006969	.006969	.006969	.006969
86	.006924	.006924	.128102	.222452	.032635
88			.000531	.000793	.000672
89	.281727	.170767	.149752	.170730	.133249
91	.406757	.246168	.215740	.260940	.191854
92	.014788	.008954	.007844	.009047	.006975
93	.036979	.022378	.019611	.022241	.017439
96			.000493	.000791	
99	.250811	.175352	.477683	.613780	.284884
100			.000714	.001124	.106053
101	.013819	.103829	.864317	.013823	.012441
103	.222440	.219245	.185221	.186677	.670792
104			.000535	.000889	
106			.000115	.000179	
107			.000040	.000068	
108			.000042	.000065	
109			.000834	.001301	
110			.000426	.000066	
TOTAL	27.019011	27.655961	30.581936	30.581936	39.268711
(K/O Ratio)					

V. BALANCE OF PAYMENTS SUBROUTINE

A. Introduction

A balance of payments adjustment model has been added to the I-O to estimate shifts in the pattern of domestic production and net exports resulting from changes in energy import levels. The routine evaluates the impacts of changes in imports of crude oil, residual fuel oil, and processed natural gas on the structure of GNP. The routine utilizes the difference in payments for these three imports between a policy case and a base case in conjunction with export and import price elasticities of demand. The routine then calculates adjustments to direct exports, net exports, and personal consumption expenditures in the GNP final demand for the policy case.

B. Assumptions

A basic assumption in this subroutine is that any variation in net exports comes at the expense of a corresponding compensating adjustment in PCE, hence, maintaining a constant level of GNP. Furthermore, the balance of payments linkage assumes that foreigners can do four things resulting from an expected increase in foreign trade dollars for their oil exports. They can directly buy more goods and services from domestic firms in the U.S. ($\text{Exports}_{\text{direct}}$); they can hoard the "oil" dollars and/or buy U.S. financial assets or real assets (U.S. Asset Transfer); they can buy more goods and services from U.S. firms producing overseas ($\text{Exports}_{\text{U.S. Overseas}}$); or they can use the "oil" dollars for currency exchange.

If they pursue the last option the value of the U.S. dollar will decrease relative to other currencies, assuming that the relative prices of all other domestic goods in the foreign market remain constant. This

dollar devaluation will then lead to more U.S. exports and less U.S. imports, Exports-Imports (\$ devaluation).

C. Subroutine

Expressing the balance of payments in current dollar format yields:

(1) $BOP = \text{Exports}_{(\text{direct})} + \text{U.S. Asset Transfer} + \text{Exports}_{(\text{U.S. Overseas})} + \text{Exports-Imports}_{(\$ \text{ devaluation})}$. A simplifying assumption is made that asset transfer and purchases from U.S. firms overseas have negligible impact on the structure of GNP. To facilitate solution of expression (1), two delta vectors have been constructed which contain estimates, by sectors, of the change in exports and net exports that result from a unit change in foreign direct demand for exports and from a unit change in foreign demand for other currencies, respectively. The balance of payments (BOP) formulation is written as

$$\begin{aligned}
 (1) \quad \Delta BOP &= P_2^{CO} (Y2_2 + Y6_2/e_{CO}) - P_1^{CO} (Y2_1 + Y6_1/e_{CO}) + \\
 &\quad P_2^{NG} (Y7_2) - P_1^{NG} (Y7_1) \\
 (2) \quad \Delta EX &= B1 \times \Delta BOP, \\
 (3) \quad \Delta NX &= B2 \times \Delta BOP, \\
 (4) \quad \Delta PCE &= P_1^{CO} (Y2_2 + Y6_2/e_{CO} - Y2_1 - Y6_1/e_{CO}) + P_1^{NG} (Y7_2 - Y7_1) \\
 &\quad - \Delta EX - \Delta NX,
 \end{aligned}$$

where

subscript 1 refers to Base Case,

subscript 2 refers to Policy Case

ΔBOP = change in the balance of payments,

P^{CO} = price of imported crude oil, 1967 \$/10⁶ Btu,

P^{NG} = price of imported, processed natural gas, 1967 \$/10⁶ Btu,

e_{CO} = processing and distribution efficiency for crude to refined oil,

ΔEX = change in direct demand for U.S. exports,

$B1$ = fraction of ΔBOP that changes direct export demand,

ΔNX = change in net export demand due to foreign exchange market revaluation of the dollar,

$B2$ = fraction of ΔBOP that changes net export demand,

ΔPCE = redistribution of productive resources to or from production of other PCE goods and services,

values for all Y's are positive or zero,

P_1^{CO} , P_2^{CO} , P_1^{NG} , P_2^{NG} , $B1$, $B2$, must be exogenously specified.

This optional subroutine makes a balance of payment 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 routine but not the balance of payments routine. Data bases are then adjusted for the second scenario, with the exception that crude oil imports, $Y(2)_{11}$, refined oil product imports, $Y(6)_{11}$, and natural gas imports, $Y(7)_{11}$, in the GNP vector of final demand are set at the solution values for the first scenario. The second scenario is then solved using both the capital investment and balance of payment subroutines. The solution for the second scenario has a different composition of GNP than the first - i.e., in net exports, capital investment, and PCE - but the same total real GNP.

Incorporating this routine into the integrated I-O/LP or reduced form model to be discussed in the I-O/LP section which follows, is analogous to the procedure for the capital investment subprogram. First,

the reduced form system is run to a convergent solution and the solution value for imported oil is compared with the value contained in the initial Y vector of final demand. A specified fraction of the increase (decreases) in foreign oil payments $B1 \times \Delta BOP$, is assigned to direct export increases (decrease) using the delta export vector, ΔEX , to disaggregate the change by sector and modify the initial export vector of final demand. Another fraction of the increase (decrease), $B2 * \Delta BOP$, is assigned to net export increase (decrease) using the delta net export vector, ΔNX , for disaggregation and additional modification of the export vector. The remaining increase (decrease) in oil imports $(1-B1-B2) * \Delta BOP$, in real terms, releases (requires) productive resources for (from) the production of other goods and services, ΔPCE , and the initial PCE vector is modified accordingly.

Next, the capital investment subprogram is run which adjusts PCE and GPFCF. A second iteration of the entire procedure is then initiated using this revised GNP. This iterative procedure continues until convergence is attained. A note on the interpretation of the final solution regarding net exports is required. In the routine, net export change to final demand are computationally treated in the export column of the disaggregated Y vector. Hence, exports and imports in all sectors except the energy supply sectors must be added together to obtain the meaningful numbers, net exports.

VI. COMBINED I-O/LP MODEL

A. Introduction

The motivation for the integration of Brookhaven's energy I-O and the BESOM (LP) system is to permit endogenous determination of specific

energy coefficients and total demands for energy products. The combination of the two models enhances the individual strengths of the systems and minimizes their independent weaknesses. In the integrated model format the A_{SS} and A_{SP} coefficients are endogenously derived from BESOM solution output. Likewise, it allows endogenous determination of interindustry demands for energy products. Only those portions which are required for GNP determination must now be specified exogenously.

The integration of the I-O with BESOM provides the capability to investigate two specific types of policy questions. First, given changes in energy prices and/or in energy technology availability in a future planning year, what will be the economy-wide impact? Second, given a policy whose initial impact lies outside the energy sectors, what will be the feedback on energy production and conversion? Analysis of the first type of policy is approached by varying constraint and parameter values within the energy model. A relative shift in fuel prices or a comparison of alternative energy technologies can be evaluated in this manner. Analysis of the second type of policy is handled by changing the GNP vector of final demand or specific I-O coefficients.

An important consideration in the linkage of the I-O coefficients and the LP systems is the estimation of the level and structure of general economic activity which can be supported from a given energy resource base. Until recently, the structure of most general equilibrium modeling efforts utilizing I-O and econometric techniques have dealt with the estimation of demand-driven equilibrium; i.e., energy demands have been derived from trend expectations of growth parameters such as population,

aggregate productivity, and consumer preferences. In this approach, resource constraints have not been emphasized.

In the BNL system, outlined in this report, structural relations have been developed between alternative energy supply activities and economic activities. This linkage permits a supply driven estimation of general equilibrium conditions. Given the increasing concern with depletable resource bases, this approach has substantial policy analysis implications when compared with the conventional methodology utilizing the demand expectations format.

While only the linkage of the I-O and BESOM is described in this paper, the use of several complementary components permits detailed analysis and evaluation of the reduced I-O/LP system output. Specifically, the Brookhaven Reference Energy System (RES) provides an accounting framework for energy flows. The Brookhaven Energy System Network Simulator (ESNS) linked to BESOM provides process specific emissions. Work is in progress to link the dynamic LP system (DESOM) with the I/O. An exogenous, iterative linkage with the DRI Long-term Interindustry Transactions Model (LITM) and the DRI Macroeconomic Growth Model provides a structural base from which to estimate the interrelationships between future growth in domestic energy consumption and future growth in aggregate domestic income, output, and employment under a wide range of possible technological, foreign trade, and government energy policy scenarios.

This DRI-BNL integration permits the assessment of two basic types of policy variables: taxes (subsidies) on energy production or consumption and energy research and development outlays to induce future commer-

cial introduction of new energy technologies. A system manual describing this linkage with the DRI combined model system is anticipated.

B. The BESOM LP System

The LP component of the integrated I/O/LP or reduced form - system has as an objective function the minimization of the total system cost of satisfying a given set of national energy product requirements. Reference 6 provides a detailed description of BESOM. Appendix IV provides a simplified description of BESOM.

Given a set of energy requirements defined by end use - i.e., motive power, space heat, and a set of available energy resources and conversion technologies - the model determines the minimum cost allocation of energy supplies to meet energy demands.

Important Characteristics of BESOM

The important characteristics of the model may be summarized as follows:

(1) The model encompasses the entire energy system including all alternative resources and both electric and nonelectric demands.

(2) The full feasible range of interfuel substitutability is reflected (as a function of relative prices and resource constraints).

(3) Technical, economic, and environmental characteristics of energy conversion devices, both supply and utilization, are incorporated.

(4) The load-duration characteristics of electrical demands are included.

(5) Supply, demand, and environmental constraints are specified exogenously.

(6) Optimal supply/demand configurations are indicated by the model. The optimization may be performed with respect to cost, resource consumption, or environmental effects in a given planning year, or with a combination of these and other factors. The system optimization is based on annualized cost in the planning year rather than a minimum present worth over some number of years.

The model is formulated as a classical transportation problem. To provide a feasible path between a supply and demand category, both a supply and demand utilizing technology must be identified. For a given path, j , a resource, S_u , is converted to intermediate energy form, Z_j , at an efficiency, e_{uj} . In turn, the intermediate energy form is used to satisfy demand D_v at an efficiency d_{vj} . Incorporation of plant capacity constraints, resource supply constraints, demand specifications and constraints on technologies, and electrical peaking and balance requirements provide detailed characterization of the national energy system. Additional constraint equations reflect pollution and attendant emissions.

The optimizing structure of BESOM is normative since it predicts the optimal mix of energy supplies that minimizes the cost per Btu of each end use.

C. I-O to BESOM Interface: Iterative Procedure

In the I-O to BESOM interface indicated in Figure 2, the vector of total outputs of energy products, X_p , is used to calculate the demand constraints for BESOM. For specific sectors there is a one-to-one correspondence between BESOM and the I-O; i.e., Btu's of space heat, air conditioning, water heat, heat, coke, petrochemical feedstocks, and

MINIMIZE $\sum_j c_j z_j$
 WITH RESPECT TO: $z_j \geq 0$
 AND:

Figure 2. Two-level iterative model.

process heat. Disaggregation in the electric power and motive power sectors and correspondence linking are, however, more complex. Definition of the various parameters is in Appendix V.

The electric power demand attributed to the local transport sector of the I-O is assigned as the BESOM demand constraint for electric mass transit and rail. The remainder of electric power output in the I-O is allocated as an exogenously specified proportion for base load and intermediate load electricity demand constraints.¹³

D. BESOM to I-O Interface: Iterative Procedure

In the linkage equations for BESOM to I-O, the I-O assumes the same production function, with the exception of fuel usage, for the BESOM supply categories which have to be aggregated.

The LP intermediate energy form solution values, Z_j , are used to calculate the coefficients for the energy supply sector rows of the modified I-O matrix; i.e., the A_{SS} and A_{SP} coefficients. The A_{SP} and A_{SS} coefficients are of the general form:

$$a_{ij} = T_{ij}/X_j$$

as defined in Table 2. Certain A_{SS} coefficients are constants since they account for conversion or transmission/distribution losses.

E. Iterative Solution Procedure

The combined model was solved by an iterative technique, however, this technique has been superseded by the I-O/LP reduced form method. The original iterative solution sequence for the combined model is as follows:

(1) A final demand vector is estimated representing GNP for the planning year. Additionally, appropriate costs, capacities, environmental specifications, and other constraints are inserted into BESOM.

(2) The basic energy demands - i.e., total outputs of the eight energy product sectors - associated with the GNP projection are determined by solving the I-O model. Exogenous specification of the A_{SS} and A_{SP} coefficients is not required since these can be endogenously derived from the combined linkage.

(3) The I-O energy product sector outputs are disaggregated, via interface equations, to obtain appropriate BESOM demand equation constraints.

(4) BESOM is run with these interface demand constraints to determine the intermediate energy form flows, Z_j , in the energy supply/demand network. For given specifications, these Z_j represent the optimal energy supply/demand configurations.

(5) The BESOM output, Z_j , is then utilized to calculate A_{SS} and A_{SP} coefficients which are inserted into the I-O.

(6) Iteration is made between the models until convergence of every element in the output, X , vector to some prespecified level is attained. If a unique solution to BESOM exists, then the combined model has a unique solution that converges.

Figure 2 shows the combined model solution sequence and Figure 3 presents the admissible LP solution variables, respectively. The interface creates a linkage between the LP admissible variables and the I-O space A-matrix coefficients. The interface consists of two basic equation sets: the I-O/LP interface deriving the LP demand constraints from the

total outputs determined in the I-O, and the LP/I-O interface deriving I-O coefficients from the BESOM solution output. The policy variables within the combined model are energy supply, capacity, environmental, other BESOM constraints, the I-O vector of final demand, and specific A-matrix coefficients.

VII. I-O/LP REDUCED FORM

A. Introduction

The reduced form methodology basically replaces the 12 LP demand equations with a reduced form set of 12 demand equations which contain the complete I-O structure. The basic linking methodology insight provided by Dantzig¹⁶ in the reduced form approach is that the I-O model variables, X_i , can be expressed as functions of the LP model variables, Z_j .

Figure 3. Admissible LP solution variables for 110 sector combined 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 CYCLE 4																						
OIL FIRED GAS TURBINE 5																						
GAS FIRED STEAM ELECTRIC 6																						
TOTAL ENERGY SYSTEMS 7																						
LIGHT WATER REACTOR 8																						
LMFBR 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																						
SNG FROM OIL 20																						
METHANE FROM COAL 21																						
COAL, UNDERGROUND 22																						
COAL, STRIPPED 23																						
H ₂ FROM ELECTROLYSIS 24																						
METHANE FROM COAL 25																						
H ₂ FROM COAL 26																						
COAL LIQUEFACTION 27																						

Note:
Shaded Activities
Denote Admissible
Solution Variables

B. Reduced Form Solution Procedure

The following generalized equation sets, expressed in matrix notation, highlight the reduced form system. The LP model equations can be represented as:

Minimize: CZ , where C represents cost vector, Z is a vector of LP variables.

Subject to:

(1) $KZ \leq b$	LP supply equations,
(2) $HZ = b'$	LP demand equations,
(3) $GZ \leq b''$	all other LP equations,
(4) $Z \geq 0$	nonnegativity requirement.

Appendix V describes the basic BESOM matrix notation.

The basic I-0 equations are written as:

(5) $(I_{ES} - A_{SS})X_{ES} - A_{SP}X_{EP} = Y_{ES}$	energy supply sectors,
(6) $-A_{PS}X_{ES} + I_{EP}X_{EP} - A_{PI}X_I = Y_{EP}$	energy product sectors,
(7) $-A_{IS}X_{ES} + (I_I - A_{II})X_I = Y_I$	nonenergy sectors,
(8) $X \geq 0$	nonnegativity constraints.

The transformation equations between the two models are divided into two groups, the energy product equations and the energy supply equations.

The energy product equations can be represented by:

(9) $JHZ = X_{EP}$,	where the 8 I-0 energy product demands,
	I-0 sectors 13 to 20, are disaggregated
	into the 12 BESOM demands using

exogenously determined allocations represented in the J transformation matrix.

The energy supply equations can be represented by:

$$(10) \quad Y_{ES} + EZ = X_{ES}, \quad \text{where the LP energy consumption flows (EZ) are added to exports, plus inventory change minus imports are equivalent to the I-O vector of domestic energy production, } (X_{ES}).$$

The linkage of the two models represents integration of a model based on domestic energy production, the I-O, and a model formulated around domestic energy consumption, the LP.

Solving I-O Eq. set (7) for X_I and then substituting into I-O, Eq. (6) yields (refer to Table A)

$$(11) \quad (-A_{PS} - A_{PI}(I_I - A_{II})^{-1}A_{IS})X_{ES} + X_{EP} = Y_{EP} + A_{PI}(I_I - A_{II})^{-1}Y_I$$

Substituting (9) and (10) into (11) to eliminate X_{ES} and X_{EP} yields

$$(12) \quad (-A_{PS} - A_{PI}(I_I - A_{II})^{-1}A_{IS})(Y_{ES} + EZ) + JHZ = Y_{EP} + A_{PI}(I_I - A_{II})^{-1}Y_I$$

Table A

<u>Coefficient of Production</u>			<u>Final Demand</u>	<u>Total Output</u>
A_{SS}	A_{SP}	0	Y_{ES}	X_{ES}
A_{PS}	0	A_{PI}	Y_{EP}	X_{EP}
A_{IS}	0	A_{II}	Y_I	X_I

Several notes regarding the interface equations should be made at this point. Specifically, Y_{ES} components for crude oil imports, natural gas imports, and the residual fuel oil imports are endogenous in the linkage structure because these variables are explicitly treated in BESOM. Also, it should be noted that the order of the I-O X_{EP} vector has been increased from 8 to 12 because of disaggregation of the I-O motive power and electric power sectors.

The resulting reduced form can then be written as

Minimize CZ

Subject to:

(13) $KZ \leq b$:	LP supply equations,
(14) Equation set (12) above:	revised LP demand equations,
(15) $GZ \leq b''$:	all other LP equations,
(16) $Z \geq 0$:	Nonnegativity constraints.

It should be noted that Eq. set (12) of the reduced form is the same order as Eq. set (2) in the original LP equation set. Additionally, energy supply matrices A_{SS} and A_{SP} can be computed from the model solution even though they are not required for solution of the reduced form. These matrices can be derived from interface equations developed for the original combined model iterative procedure where both models were run independently.

In the I-O structure there is an inherent redundancy in the model in terms of specification of the energy supply/conversion sectors, 1 to 12, and the energy product sectors, 13 to 20. Neglecting imports, exports,

and inventory change, both sets of transactions represent total domestic energy consumption. The only difference between the two sectors is the Btu units of measure. Thus, in arriving at Eq. (12), we only had to consider Eq. (6) and (7), and not (5).

C. I-O/LP Reduced Form Program - PDS Version

An example of the reduced form linking equations for one particular set of BESOM and I-O data bases is shown in Table 11. Specifically, the revised 12 LP demand constraint equations in Eq. set (12) of the LP reduced form, as listed again below, are Eq. RED01 through RED12 in Table 11.

$$(12) \quad (-A_{PS} - A_{PI}(I_I - A_{II})^{-1}A_{IS}) * (Y_{ES} + F_S Z) + \\ F_P Z = Y_{EP} + A_{PI}(I_I - A_{II})^{-1}Y_I.$$

Table 12 identifies the LP variables and reduced form coefficient in Eq. RED01, demand for coke. Coefficients in this equation reflect A matrix coefficient and LP conversion efficiencies. Reference to Table 13 presents a reference energy system flow diagram to identify the inputs to the specific energy product sectors indicated in the energy product demand column. This allows correlation of the IEF flows in the diagram with the LP input categories tabulated for each IEF to energy product demand in the RED(XX) LP demand equations in Table 11.

The demand equations in BESOM become nonbinding and, as indicated by a sample, demand specification RED(XX), in Table 12, the reduced form of the I-O is embodied in the LP demand constraints. There are 12 reduced form LP demand constraints due to disaggregation of the intermediate load

Reduced Form Demand Equations

[illegible]

Table 12

Typical Demand Equation for Ore Reduction
Feedstocks - i.e. Coke (RED 01)

Intermediate
Energy Form

	LP Variable	Coefficient *
TCOA11		
EE	Electricity Generation	
(Coal-Coke)	01 Coal Steam	
	03 Oil Steam	
	04 Oil Combined Cycle	
	05 Gas Turbine	.02807 Btu Conversion Coefficients
	06 Gas Steam	
	TE Total Energy System	
	ST Steam Topping System	
	GT Gas Turbine	
	FC Fuel Cell	
	11 Hydroelectric	.02357
	12 Geothermal	
	13 Solar Electric	
	14 Pumped Storage	
	16 GAS Gas from Domestic Crude Oil (Oil Gasification)	
	17 GAS Gas from Imported " " "	
	18 GAS Gas from Shale Oil "	
	19 GAS Gas from Domestic Natural	
	22 GAS Gas from Underground Coal (Coal Gasification)	.00126
	23 GAS Gas from Strip Coal	
	22 HYD Hydrogen from Underground Coal	
	22 LBG Low Btu Gas " " "	
	23 HYD Hydrogen from Strip Coal	
	23 LBG Low Btu Gas " " "	
Resource	RR 16 Domestic Crude	.00738
	RR 19 Domestic Natural Gas	
	RR 22 Underground Coal	.00125
	RR 23 Strip Coal	
	16 OIL Oil from Domestic Crude	
	17 OIL Oil from Imported Crude	
	18 OIL Oil from Shale Crude	
	22 OIL Oil from Underground Coal	.00624
	22 MET Methanol from " "	
	23 OIL Oil from Strip Coal	
	23 MET Methanol from Strip Coal	

* These coefficients embody the activity coefficient, a_{ij} , as well as conversion loss coefficients.

Reference Energy System, Year

electric power demand of the I-O into electric base load intermediate loads and electric rail and the disaggregation of the motive power demand of I-O into air transport demand and truck, bus, nonelectric rail, and car demand. Table 14 lists these reduced form constraint equations.

Table 15 presents the transformation Eqs. (9) and (10) for the reduced form model. These transformation equations, $T(I,J)$, permit calculation of I-O A_{SS} and A_{SP} coefficients from LP output. Appendix VI provides a listing of the updated LP terms used in the reduced form specifications.

Referring to the flow diagram for the PDS version of the reduced form system, Figure 4 indicates the basic structure of the model. Specifically, in program 1 (Prog. 1), the reduced form equations map the I-O row equations into a set of 12 demand equations, with LP variables, Z 's, replacing the I-O variables, X 's. The inputs to Prog. 1 are the I-O A -matrix coefficients, except the A_{SS} and A_{SP} coefficients which can be determined endogenously, and the exogenously specified GNP final demand matrix. Component mappings in the development of the reduced form equations are: (1) the mapping of resources, $RR(RS)$, in the LP system to I-O supply sectors 1 to 3, (2) the mapping of electricity generation systems in the LP, $EE: X(CS)DM$, to the appropriate I-O sectors 8 to 12, and (3) the mapping of the resource IEF's in the LP to the corresponding I-O sectors 4 to 7. Specification of the reduced form demand equations is facilitated by generating the following matrix tables:

$$(1) -A_{PS} - A_{PI}(I_I - A_{II})^{-1}A_{IS},$$

$$(2) A_{PI}(I_I - A_{II})^{-1}Y_I,$$

and

Table 14

Active Constraints Added to Reduced Form Model

- RED01 = demand constraint derived by I-0 for ore reduction.
- RED02 = demand constraint derived by I-0 for chemical feedstock.
- RED03 = demand constraint derived by I-0 for air transport, a specified fraction of the total I-0 derived for motive power.
- RED04 = demand constraint derived by I-0 for process heat.
- RED05 = demand constraint derived by I-0 for water heat.
- RED06 = demand constraint derived by I-0 for space heat.
- RED07 = demand constraint derived by I-0 for air conditioning.
- RED08 = demand constraint derived by I-0 for intermediate load electric power, a specified fraction of the I-0 demand for total electric power.
- RED09 = (ratio 1) D01 + (ratio 2) D02 = 0
- RED10 = (ratio 3) D02 + (ratio 4) D21 = 0
- RED11 = (ratio 5) D19 + (ratio 6) D20 = 0
- RED12 = (ratio 7) D19 + (ratio 8) D22 = 0

where D01, D02, D21, D19, D20, D22 are left-hand-side parts of BESOM demand equations, and ratio 1, ...ratio 8 are coefficients defined in Table Ratios in the reduced form matrix generator program.

RED09 and RED10 are demand constraints for miscellaneous electric base load and electric rail demands as fractions of the I-0 demand for intermediate load electric power.

RED11 and RED12 are demand constraints for truck, rail, and automobile demands as functions of the I-0 demand for air transport.

The D(XX) refer to energy product demands as defined in the LP. The reduced form mapping tables referred to above are derived from computer output. These tables and their corresponding formats essentially map the LP and I-0 demand linkages for computation of the transaction coefficients; i.e., $T(I,J)$, of the I-0 energy matrix for sectors 1 to 20.

Table 15

Transformation Equations Used in I-O/LP
Reduced Form Model for Outputs of Energy Sectors

- $X(I)$ = total output for I-O sector I
(In the reduced model these are used in the calculations of Eq. REDO-1 to REDO-8 and they are also respecified free rows in the LP to calculate total outputs and A-matrix coefficients, A_{SS} , and A_{SP} , upon solution of LP.)
- $T(I,J)$ = transaction from sector I to J; $T_{ij} = a_{ij}X_j$
(In the reduced model, they are free rows to calculate A-matrix coefficients, A and A , upon solution of LP.)
- $Y(I,01)$ = Σ Final Demand nonimport components for I-O sector I.
- $Y(I,02)$ = Σ Final Demand import for components I-O sector I.
- $X(1)$ = $RR22 + RR23 + \left[Y(1,01) + Y(1,02) \right] + \frac{1}{CSE \text{ eff}} \times$
 $\frac{1}{\text{coal cleaning eff}} \left[Y(8,01) + Y(9,02) \right].$
- $X(2)$ = $RR16 + RR19 + Y(2,01) + \frac{1}{\text{oil ref}} Y(6,01) + \frac{1}{NG \text{ Proc}} Y(7,01).$
- $X(3)$ = $RR18.$
- $X(4)$ = $\frac{1}{NG \text{ Trans eff}} (22GAS + 23GAS + 22LBG + 23LBG).$
- $X(5)$ = $22OIL + 23OIL + 22MET + 23MET.$
- $X(6)$ = $16OIL + 17OIL + 18OIL + 22OIL + 23OIL + 22MET + 23MET$
 $+ Y(6,01).$
- $X(7)$ = $\frac{1}{NG \text{ Trans eff}} (16GAS + 17GAS + 18GAS + 19GAS + 22GAS$
 $+ 22HYD + 23GAS + 23 \text{ HYD} + Y(7,01).$
- $X(8)$ = $EE02.$
- $X(9)$ = $EE01 + EE03 + EE04 + EE05 + EE06 + EETE + EEST + EEGT$
 $+ Y(9,01) + Y(9,02).$
- $X(10)$ = $EE08.$
- $X(11)$ = $EE09 + EE10.$

Table 15 (cont'd.)

$$X(12) = EE11 + EE12 + EE13 + EE14 + EEFC.$$

$$X(13) = D11, \\ = \sum_{\substack{D \\ IEF}} ((D) (IEF) 11) (\text{end use eff}).$$

$$X(14) = D12 \\ = \sum_{\substack{D \\ IEF}} ((D) (IEF) 12) (\text{end use eff}).$$

$$X(15) = D19 + D20 + D22, \\ = \sum_{\substack{D \\ IEF, \\ DM = 19, 20, 22}} ((D) (IEF) (DM)) (\text{end use eff})$$

$$X(16) = D09, \\ = \sum_{\substack{D \\ IEF}} ((D) (IEF) 09) (\text{end use eff})$$

$$X(17)^* = D17, \\ = \sum_{\substack{D \\ IEF}} ((D) (IEF) 17) (\text{end use eff}).$$

$$X(18) = D14, \\ = \sum_{\substack{D \\ IEF}} ((D) (IEF) 14) (\text{end use eff}).$$

*Note: The expression $X(17) = D17,$

$$= \sum_{\substack{n \\ IEF}} ((D) (IEF) (DM) (\text{end use eff}))$$

is the total output from I-O energy product sector (17) equated to LP total demand category 17. The LP summation is translated as the LP IEF's utilizing device D to meet energy product demand DM summed over relevant devices and IEF's. In the case of electricity demands the notion of end-use device is replaced by the specific electricity demand itself.

Table 15 (cont'd.)

$$X(19) = D16, \\ = \sum_{\substack{D \\ IEF}} ((D) (IEF) 16) \text{ (end use eff).}$$

$$X(20) = D01 + D02 + D21, \\ = \sum_{\substack{D \\ IEF}} ((D) (IEF) (DM)) \text{ (end use eff),} \\ DM = 01, 02, 03.$$

T_{IJ} Coefficients for Calculations of A_{SS} & A_{Sp} Coefficients $[T_{ij} = a_{ij} X_j]$

$$\begin{aligned} T(1,4) &= (1/\text{coal gas conv. eff.}) (22GAS + 23GAS) \\ &\quad + (1/\text{coal LBG conv. eff.}) (22LBG + 23LBG) \\ T(1,5) &= (1/\text{syn oil conv. eff.}) (22OIL + 23OIL) \\ &\quad + (1/\text{methanol conv. eff.}) (22MET + 23MET) \\ T(1,7) &= (1/\text{HYD conv. eff.}) (22HYD + 23HYD) \\ T(1,8) &= (1/\text{coal cleaning eff.}) (FFCOA02) \\ T(1,9) &= (1/\text{coal cleaning eff.}) (FFCOA01 + FFCOAST + FFCOAGT) \\ &\quad + (1/\text{CSE eff.} * \text{coal cleaning eff.}) (Y(9,01) + Y(9,02)) \\ T(1,13) &= (1/\text{coal cleaning eff.}) (TCOA11) \\ T(1,14) &= (1/\text{coal cleaning eff.}) (TCOA12) \\ T(1,16) &= (1/\text{coal cleaning eff.}) (TCOA09 + SCOA09 + GCOA09) \\ T(1,18) &= (1/\text{coal cleaning eff.}) (TCOA14) \\ T(2,2) &= (1-\text{oil ref. eff.}) (RR16 + RR17) + (1-\text{NG proc. eff.}) (RR19) \\ &\quad + \frac{(1-\text{oil ref. eff.})}{\text{oil ref. eff.}} Y(6,01) + \frac{(1-\text{NG proc. eff.})}{\text{NG Proc. eff.}} Y(7,01) \\ T(2,6) &= 16OIL + 17OIL + Y(6,01) \\ T(2,7) &= \frac{\text{oil ref. eff.}}{\text{oil gas conv. eff.}} (16GAS + 17GAS) \\ &\quad + \frac{1}{\text{NG trans eff.}} (19GAS + Y(7,01)) \\ T(3,3) &= (1-\text{oil ref. eff.}) RR18 \\ T(3,6) &= 18OIL \end{aligned}$$

Table 15 (cont'd.)

T(3,7)	= $\frac{1}{\text{NG trans eff}}$ 18GAS
T(4,7)	= (22GAS + 23GAS + 22LBG + 23LBG) $\frac{1}{\text{NG trans eff}}$
T(5,6)	= 22OIL + 23OIL + 22MET + 23MET
T(6,9)	= FFOIL03 + FFOIL04 + FFOIL05 + FFOILTE + FFOILST + FFOILGT
T(6,12)	= FFOILFC + FFMETFC
T(6,14)	= TOIL12
T(6,15)	= TOIL19 + TOIL20 + TOIL22
T(6,16)	= TOIL09 + SOIL09 + GOIL09
T(6,17)	= TOIL17
T(6,18)	= TOIL14
T(7,7)	= $\frac{(1-\text{NG trans eff})}{\text{NG tran eff}}$ (16GAS + 17GAS + 18GAS + 19GAS + 31GAS + 22HYD + 23HYD)
T(7,9)	= FFGAS06 + FFGASST + FFGASGT
T(7,12)	= FFGASFC
T(7,14)	= TGAS12
T(7,15)	= TGAS19
T(7,16)	= TGAS09 + SGAS09 + GGAS09
T(7,17)	= TGAS17
T(7,18)	= TGAS14
T(7,19)	= TGAS16
T(8,8)	= EE02 (1-elec trans eff)
T(8,12)	= X0204
T(8,15)	= X0222
T(8,16)	= X0209
T(8,17)	= X0217
T(8,18)	= X0214

Table 15 (cont'd.)

T(8,19)	= X0216
T(8,20)	= X0201 + X0202 + X0203 + X0221
T(9,9)	= (EE01 + EE03 + EE04 + EE05 + EE06) (1-elec trans eff)
T(9,12)	= X0104 + X0304 + X0404 + X0504 + X0604
T(9,15)	= X0122 + X0322 + X0422 + X0522 + X0622 + XTE22
T(9,16)	= X0109 + X0309 + X0409 + X0509 + X0609
T(9,17)	= X0117 + X0317 + X0417 + X0517 + X0617
T(9,18)	= X0114 + X0314 + X0414 + X0514 + X0614
T(9,19)	= X0116 + X0316 + X0416 + X0516 + X0616
T(9,20)	= X0101 + X0102 + X0103 + X0121 + X0301 + X0302 + X0303 + X0321 + X0401 + X0402 + X0403 + X0421 + X0501 + X0502 + X0503 + X0521 + X0601 + X0602 + X0603 + X0621 + XTE01 + XTE02 + XTE03 + XST01 + XST02 + XST03 + XGT01 + XGT02 + XGT03
T(10,10)	= EE08 (1-elec trans eff)
T(10,12)	= X0804
T(10,15)	= X0822
T(10,16)	= X0809
T(10,17)	= X0817
T(10,18)	= X0814
T(10,19)	= X0816
T(10,20)	= X0801 + X0802 + X0803 + X0821
T(11,11)	= (EE09 + EE10) (1-elec trans eff)
T(11,12)	= X0904 + X1004
T(11,15)	= X0922 + X1022
T(11,16)	= X0909 + X1009
T(11,17)	= X0917 + X1017
T(11,18)	= X0914 + X1014

Table 15 (cont'd.)

$$T(11,19) = X0916 + X1016$$

$$T(11,20) = X0901 + X0902 + X0903 + X0921 + X1001 + X1002 \\ + X1003 + X1021$$

$$T(12,12) = \frac{(1-\text{elec trans eff})}{\text{elec trans eff}} (X1101 + X1102 + X1103 + X1109) \\ + X1114 + X1116 + X1117 + X1121 + X1122 + X1201 + X1202 \\ + X1203 + X1214 + X1216 + X1217 + X1221 + X1222 + X1401 \\ + X1402 + X1403 + X1409 + X1414 + X1416 + X1417 + X1421 \\ + X1422 + (1-\text{elec trans eff}) (X1104 + X1204 + X1404)$$

$$T(12,15) = X1122 + X1222 + X1422$$

$$T(12,16) = X1109 + X1409$$

$$T(12,17) = X1117 + X1217 + X1417$$

$$T(12,18) = X1114 + X1214 + X1414$$

$$T(12,19) = X1116 + X1216 + X1416$$

$$T(12,20) = X1101 + X1102 + X1103 + X1121 + X1201 + X1202 + X1203 \\ + X1221 + X1301 + X1302 + X1303 + X1401 + X1402 + X1403 \\ + X1421$$

Figure 4. PDS version of the I-O/LP reduced form system.

(3) the final demand vector Y_{ES} for import and nonimport classifications.

Program 2 (Prog. 2) combines the data tables generated in Prog. 1 with the BESOM tables and generates the reduced form matrix for input to the APEX LP optimization package. Program 3 outputs are the $T(I,J)$'s and $A(I,J)$'s for $I = 1, 12$ and $J = 1, 20$; a revised energy final demand solution resulting from the LP variables of imported oil, imported processed gas, and imported residual fuel oil; and total energy outputs X_S and X_P . In this solution the system outputs are results of the LP variables; i.e., the X_S and X_P are functions of the LP variables.

Program 4 output is the revised energy final demand values and the A-matrix energy coefficients. The Y-vector is updated as a function of the LP solution variables for imported crude oil, imported gas, and imported residual fuel oil. In the previous steps the solutions for the $I=0$ $X(I)$, $I = 1, 20$ are functions of the LP solution variables, Z 's.

In Program 5, (Prog. 5) energy imports and A-matrix energy coefficients from the model solution are combined with the original A and Y matrices for determination of the nonenergy X vector. In this step the values for X_S and X_P are also determined from inversion of the complete $(I-A)$ matrix. Comparison of the values for X_I , X_S , and X_P determined by the LP APEX solution with those calculated from the $(I-A)$ matrix inversion provides a consistency check on the interface equation relationships of X_S , X_P , A_{SS} , and A_{SP} with the LP Z_j 's.

Reference to Appendix VII outlines the basic operational steps for running the reduced form model.

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Appendix I

Sectoral Classification of BNL Energy Input-Output Model and Alignment with Other Classification Systems

BNL 110	Sector	BNL 101	BEA	Battelle	A. Carter	BLS	DRI 18
1	Coal	1	7	7	7	8	5
2	{ Crude Oil }	2	8	8	8	9	{ 6
	{ Crude Gas }						10
3	Shale Oil	-	-	-	-	-	15
4	Methane from coal	3	-	-	-	-	17
5	Coal liquefaction	-	-	-	-	-	16
6	Refined oil products	4	31.01	part 31	part 41	part 42	7
7	Pipeline gas	5	68.02	68.2	93	102	9
8	Coal combined cycle electric	-	-	-	-	-	-
9	Other fossil electric	6	68.01 78.02 79.02	-	-	-	8
10	LWR electric	7	68.01 78.02 79.02	-	-	-	-
11	HTGR electric	-	-	68.1	.92 part 104	101 123 part 123	11
	Hydroelectric	8	68.01 78.02 79.02	-	-	-	12
12	Geothermal	-	-	-	-	-	13
	Solar electric	-	-	-	-	-	14
	Solar direct	-	-	-	-	-	18
13	Ore 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 ferroalloys ores mining	21	5	5	5	5	-
26	Nonferrous metal ores mining	22	6	6	6	6-7	-
27	Stone and clay mining, quarrying	23	9	9	9	10	1
28	Chemicals and fertilizer mineral mining	24	10	10	10	11	-
29	New construction, residential buildings	25	11.01	11.1	11	12	-
30	New construction, nonresidential buildings		11.02	11.2	12	13	-
31	New construction, public utilities		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	-	-
35	Maintenance and repair construction, all other		12.02	12.2	17	17	-
36	Ordnance and accessories	27	13	13	18	18-19	-
37	Food and kindred products	28	14	14	19	20	-
38	Tobacco manufacturers	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, p. 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	2
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	31.02	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	-

Appendix I
Sectoral Classification of BNL Energy Input-Output Model
and Alignment with Other Classification Systems

BNL 110	Sector	BNL 101	BEA	Battelle	A. Carter	BLS	DRI 18
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 prod., 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	2
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, urban and interurban highway pass. trans.	81	{ 65.02 79.01 }	65.2	84	94	
91	Motor freight transportation and warehousing	82	65.03	65.3	85	95	3
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	4
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	{ 78.01 78.04 }	-	part 104	{ 122 124 }	
108	State and local government enterprises	99	79.03	-	part 105	part 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	130	
-	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 - Brookhaven National Laboratory 110 sector version
 BNL 101 - Brookhaven National Laboratory 101 sector version
 BEA - Bureau of Economic Analysis, U.S. Dept. of Commerce
 Battelle- Battelle Memorial Institute; used in An "Ex Ante" Capital Matrix for the United States, 1970-1995
 A.Carter- Professor Ann Carter, Brandeis University
 BLS - Bureau of Labor Statistics, U.S. Dept. of Labor
 DRI 18 - Data Resources, Inc. 18 sector Interindustry model

APPENDIX II

A. Energy Supply/Conversion Sectors

The first 12 sectors of the I-O are energy supply/conversion sectors which transform basic energy resources into usable (product) forms of energy capable of meeting final, end-use demand. They depict actual, physical production processes and are defined below.

1. Coal

The coal sector produces raw coal as it comes from the mine, and total output is measured in Btu's of raw coal. It is assumed that sectors purchasing this coal do their own crushing and cleaning.

2. Crude Oil & Gas

This sector's total output is the summation of Btu's of crude oil at the wellhead and Btu's of associated and nonassociated wellhead gas that are produced domestically. As an accounting convenience, processing losses for domestic gas and refining losses for both imported and domestic crude oil are represented by the diagonal A-matrix coefficient for this sector.* This permits energy transfer from the crude oil and gas sector to the refined oil products sector to be measured by Btu's of refined oil products. It also permits energy transfer to the pipeline gas sector to be measured by Btu's of processed gas.

* Whether or not one accounts for energy conversion or distribution losses is immaterial as long as one is not formulating the I-O itself as an optimization model. What is crucial, however, is the unit of measurement adopted for total output (total domestic production) from each energy supply sector. This measure must correspond with the units used to renormalize I-O coefficient column vectors for the energy sectors from dollars of input per dollar of output to dollars of input per Btu of output.

3. Shale Oil

The shale oil sector produces a crude oil substitute, and total output is measured in terms of Btu's of crude oil. As an accounting convenience, refining losses are represented by the diagonal A-matrix coefficient, and this sector actually transfers Btu's of refined oil products to the refined oil products sector.

4. Methane from Coal

This sector produces a high Btu, pipeline-quality synthetic gas from coal by the HYGAS process. The coal input is considered to be raw coal, the same unit of measure as the output of the coal sector. The gas produced is a direct substitute for processed natural gas, and all of it is delivered to the pipeline gas sector.

5. Synthetic Oil from Coal

This sector originally produced desulfurized coal by a solvent refining process, a boiler fuel for electricity generation. Since this sector now produces a different product, a synthetic oil via coal liquefaction, new costs and conversion efficiencies have been calculated and inserted into BESOM.

6. Refined Oil Products

This sector refines all imported and domestic crude oil, domestic shale oil, and domestic liquefied coal. Its output is measured by Btu's of refined petroleum products, and imports of refined products are not included in the measure of domestic production.

7. Pipeline Gas

This sector, in essence, distributes high Btu, pipeline-quality gas, and total output is measured by Btu's of processed gas produced

domestically. Total output does not include imported pipeline gas from Canada or imported LNG, substitutes for that produced domestically. Consumption of gas by pipeline pumping stations is accounted for by a "loss" coefficient in the diagonal A-matrix entry for this sector. Transfers of gas to other sectors are therefore measured by Btu's of delivered gas at the point of utilization.

8. Coal Combined-Cycle Electric

This sector produces electricity by the combined low-Btu coal gasification and COGAS generation processes. Total output is measured by Btu's of generated electricity. Transmission and distribution losses are tabulated in the diagonal A-matrix entry for this sector, and distribution to all other sectors is measured by Btu's of distributed electricity, conventions adopted for all of the electric generation sectors.

9. Other Fossil Electric

This sector combines electricity production from conventional coal-fired boilers, oil-fired boilers, gas-fired boilers, oil-fired gas turbines, oil-fired steam electric combined cycle, and oil-fired total energy systems.

10. LWR Electric

This sector produces electricity from light water nuclear reactors.

11. HTGR Electric

This sector produces electricity from high-temperature gas-cooled reactors.

12. Hydroelectric

This sector combines electricity production from (1) hydroelectric generation plants; (2) geothermal steam electric-generating plants; (3) pumped storage plants; and (4) solar electric central installations. Electrical transmission losses in the diagonal element of the A matrix are represented for the first two and the last electric generation methods, but not for pumped storage.

B. Energy Product Sectors

Eight dummy, energy product sectors are included in the 110 sector I-O model, the same as in the 101 sector model. Input-output energy product sector definitions and the new numbering scheme are listed below.

13. Ore Reduction Feedstocks, ORF

This sector distributes coke for ore reduction purposes.

14. Chemical Feedstocks, CF

This sector distributes feedstocks for chemical industries in the raw form used by those industries such as naphtha or methane, as well as lubricants and greases used by all industries.

15. Motive Power, MP

This sector's output is measured in terms of power available at a drive shaft for transport purposes regardless of the fuel used to provide that power. Electric rail transport is not included, however.

16. Process Heat, PH

This sector supplies all heating requirements including industrial process heat, cooking heat, and clothes drying.

17. Water Heat, WH

The output of this sector is measured in terms of Btu's of heat added to water for any purpose other than steam for process heat or space heat.

18. Space Heat, SH

The output of this sector is measured in terms of Btu's of heat added to a building regardless of fuel or type of heating system.

19. Air Conditioning, AC

This sector's output is Btu's of heat removed from the air being conditioned.

20. Electric Power, EP

This sector's output includes all nonsubstitutable uses of transmitted and distributed electricity such as lighting, appliances, other electric drive, industrial electrolysis, etc. Electricity used for motive power in electric rail and mass transit systems is also included in this sector.

Appendix III

1985 Coal Mining Coefficients

BNL 110	A-MATRIX COEFFICIENTS		BNL 110	A-MATRIX COEFFICIENTS	
1	0	BTU/BTU	56	.002392	1967\$/10 ⁶ BTU
2	0		57	0	
3	0		58	0	
4	0		59	0	
5	0		60	.000141	
6	0		61	.004562	
7	0		62	.000005	
8	0		63	0	
9	0		64	0	
10	0		65	0	
11	0		66	.001157	
12	0		67	.004883	
13	0		68	0	
14	.000004		69	.008829	
15	.000079		70	.000070	
16	.000527		71	.000460	
17	.000006		72	0	
18	0		73	.000231	
19	0		74	.001213	
20	.000133		75	0	
21	0	1967 \$/10 ⁶ BTU	76	0	
22	0		77	.000665	
23	0		78	0	
24	0		79	.001294	
25	.000004		80	0	
26	.000017		81	0	
27	.000062		82	.000083	
28	.000004		83	.000113	
29	0		84	0	
30	0		85	.000564	
31	0		86	0	
32	0		87	0	
33	0		88	0	
34	0		89	.001275	
35	.000450		90	0	
36	0		91	.001014	
37	0		92	.000044	
38	0		93	.000126	
39	0		94	.000010	
40	0		95	.000014	
41	0		96	.000577	
42	0		97	0	
43	.001340		98	.000139	
44	0		99	.005403	
45	0		100	.002861	
46	0		101	.005127	
47	.000092		102	0	
48	0		103	.004776	
49	.000004		104	.000783	
50	.003357		105	0	
51	0		106	.000175	
52	0		107	.000166	
53	0		108	.000042	
54	.000079		109	.000939	
55	.000029		110	.000049	

Appendix III (cont'd.)

1985 Crude Oil and Gas Extraction Coefficients

BNL 110	A-MATRIX COEFFICIENTS		BNL 110	A-MATRIX COEFFICIENTS	
1	0	BTU/BTU	56	.000899	1967\$/10 ⁶ BTU
2	.024703		57	0	
3	0		58	0	
4	0		59	0	
5	0		60	.001169	
6	0		61	.002112	
7	0		62	0	
8	0		63	0	
9	0		64	.001858	
10	0		65	0	
11	0		66	.000751	
12	0		67	.001308	
13	0		68	0	
14	.003003		69	.001555	
15	.000059		70	0	
16	.011095		71	0	
17	.000004		72	0	
18	0		73	.001670	
19	0		74	.000027	
20	.003799		75	0	
21	0	1967\$/10 ⁶ BTU	76	0	
22	0		77	.004485	
23	0		78	0	
24	0		79	.000020	
25	0		80	.000247	
26	.000006		81	.001938	
27	0		82	.000052	
28	0		83	.003027	
29	0		84	0	
30	0		85	0	
31	0		86	.000243	
32	0		87	0	
33	0		88	0	
34	0		89	.002074	
35	.007193		90	0	
36	0		91	.001649	
37	0		92	.000073	
38	0		93	.000205	
39	0		94	.000017	
40	.000146		95	.000024	
41	0		96	.000939	
42	0		97	0	
43	.000003		98	.000226	
44	0		99	.009787	
45	0		100	.004652	
46	0		101	.008338	
47	.000093		102	0	
48	0		103	.007767	
49	.000024		104	.001273	
50	.005400		105	0	
51	0		106	.000285	
52	0		107	.000271	
53	.000240		108	.000069	
54	.000132		109	.001527	
55	.000048		110	.000080	

Appendix III (cont'd.)

1985 Refined Oil Products Coefficients

BNL 110	A-MATRIX COEFFICIENTS		BNL 110	A-MATRIX COEFFICIENTS	
1	0	BTU/BTU	56	.000117	1967\$/10 ⁶ BTU
2	1.0004000		57	.000085	
3	0		58	.000064	
4	0		59	0	
5	0		60	.005162	
6	.030534		61	.000117	
7	0		62	.003951	
8	0		63	.012530	
9	0		64	.000664	
10	0		65	0	
11	0		66	.000610	
12	0		67	0	
13	0		68	0	
14	.000100		69	0	
15	.000006		70	.000546	
16	.043881		71	0	
17	.000004		72	.000010	
18	.000110		73	.000235	
19	.000136		74	.000021	
20	.002191		75	0	
21	0	1967 \$/10 ⁶ BTU	76	0	
22	0		77	0	
23	0		78	0	
24	0		79	0	
25	0		80	.000042	
26	0		81	0	
27	.007164		82	.000042	
28	.000053		83	.000010	
29	0		84	0	
30	0		85	0	
31	0		86	.000096	
32	0		87	.000149	
33	0		88	.000278	
34	0		89	.002698	
35	.010817		90	0	
36	0		91	.010024	
37	.001788		92	.003909	
38	0		93	.000257	
39	0		94	.013097	
40	.000010		95	.019631	
41	.000289		96	.004134	
42	0		97	0	
43	.000524		98	.002345	
44	.000021		99	.037131	
45	0		100	.025800	
46	0		101	.029109	
47	.009381		102	.000385	
48	.004690		103	.052457	
49	.000096		104	.000846	
50	.045795		105	0	
51	.000042		106	.000235	
52	.003973		107	.001285	
53	.001692		108	.000160	
54	.005537		109	.002934	
55	.002088		110	.000395	

Appendix III (cont'd.)

1985 Pipeline Gas Coefficients

BNL 110	A-MATRIX COEFFICIENT		BNL 110	A-MATRIX COEFFICIENTS	
1	0	BTU/BTU	56	.000093	1967 \$/10 ⁶ BTU
2	.979534		57	0	
3	0		58	0	
4	0		59	0	
5	0		60	0	
6	0		61	0	
7	.032490		62	0	
8	0		63	0	
9	0		64	0	
10	0		65	0	
11	0		66	0	
12	0		67	0	
13	0		68	0	
14	.000004		69	0	
15	.000072		70	0	
16	0		71	0	
17	.000028		72	0	
18	.000467		73	0	
19	.000076		74	.000023	
20	.000224		75	0	
21	0	1967 \$/10 ⁶ BTU	76	0	
22	0		77	0	
23	0		78	0	
24	0		79	.000007	
25	0		80	0	
26	0		81	0	
27	0		82	.000046	
28	0		83	.000007	
29	0		84	0	
30	0		85	0	
31	0		86	0	
32	0		87	0	
33	0		88	0	
34	0		89	.000156	
35	.008602		90	0	
36	0		91	.001290	
37	0		92	.000602	
38	0		93	.000015	
39	0		94	.002776	
40	0		95	.004160	
41	.000156		96	.005481	
42	0		97	0	
43	0		98	.000250	
44	0		99	.005481	
45	0		100	.009947	
46	0		101	.007640	
47	.000555		102	0	
48	0		103	.033876	
49	.000054		104	.001610	
50	.000031		105	0	
51	0		106	.000328	
52	0		107	.003605	
53	0		108	.021974	
54	.000156		109	.005614	
55	.000054		110	.000336	

Appendix III (cont'd.)

1985 High BTU Coal Gasification Coefficients
(Methane from Coal)

BNL 110	A-MATRIX COEFFICIENTS		BNL 110	A-MATRIX COEFFICIENTS	
1	1.620743	BTU/BTU	56	.00015	1967 \$/10 ⁶ BTU
2	0		57	0	
3	0		58	0	
4	0		59	.00002	
5	0		60	.00008	
6	0		61	.00016	
7	0		62	.00045	
8	0		63	.00024	
9	0		64	0	
10	0		65	0	
11	0		66	.00011	
12	0		67	0	
13	0		68	0	
14	.00003		69	.00043	
15	.00301		70	.00004	
16	0		71	.00009	
17	0		72	.00026	
18	.00011		73	.00016	
19	.00014		74	0	
20	.00219		75	0	
21	0	1967 \$/10 ⁶ BTU	76	0	
22	0		77	.00003	
23	0		78	0	
24	0		79	.00003	
25	0		80	0	
26	0		81	0	
27	.01749		82	0	
28	0		83	.00002	
29	0		84	0	
30	0		85	0	
31	0		86	.00002	
32	0		87	.00001	
33	0		88	.00002	
34	0		89	.00174	
35	.00910		90	0	
36	.00001		91	.00100	
37	0		92	.00174	
38	0		93	.00005	
39	.00011		94	.00045	
40	.00001		95	0	
41	.00002		96	.00092	
42	.00002		97	0	
43	.00004		98	.01324	
44	0		99	.00085	
45	0		100	.02313	
46	0		101	.00387	
47	.00096		102	.00017	
48	.00018		103	.00557	
49	.00054		104	.00018	
50	.00549		105	0	
51	0		106	.00011	
52	.00053		107	0	
53	.00012		108	0	
54	0		109	.00147	
55	0		110	.00018	

Appendix III (cont'd.)

1985 Shale Oil Coefficients

BNL 110	A-MATRIX COEFFICIENT		BNL 110	A-MATRIX COEFFICIENT	
1	0	BTU/BTU	56	.002057	1967 \$/10 ⁶ BTU
2	0		57	0	
3	0		58	0	
4	0		59	0	
5	0		60	0	
6	0		61	0	
7	0		62	0	
8	0		63	0	
9	0		64	.000072	
10	0		65	.001104	
11	0		66	.000590	
12	0		67	.000890	
13	0		68	0	
14	.000001		69	.006994	
15	.000015		70	.000854	
16	.000097		71	0	
17	.000001		72	0	
18	0		73	.002496	
19	0		74	0	
20	.000025		75	0	
21	0	1967 \$/10 ⁶ BTU	76	0	
22	0		77	.002246	
23	0		78	0	
24	0		79	0	
25	0		80	.000821	
26	0		81	0	
27	0		82	0	
28	0		83	.000618	
29	0		84	0	
30	0		85	0	
31	0		86	.000619	
32	0		87	0	
33	0		88	0	
34	0		89	.000443	
35	.008060		90	.000253	
36	0		91	.000443	
37	0		92	0	
38	0		93	.000013	
39	0		94	.000114	
40	0		95	0	
41	0		96	.001189	
42	0		97	0	
43	0		98	.001878	
44	0		99	.003786	
45	0		100	.025971	
46	0		101	.022496	
47	0		102	.000149	
48	0		103	.007763	
49	.000154		104	.002639	
50	.030320		105	0	
51	0		106	.001139	
52	0		107	0	
53	0		108	0	
54	0		109	.001713	
55	0		110	.000173	

Appendix III (cont'd.)

1985 High Temperature Gas-Cooled Reactor Coefficients

BNL 110	A-MATRIX COEFFICIENTS		BNL 110	A-MATRIX COEFFICIENTS	
1	0	BTU/BTU	56	.00504	1967 \$/10 ⁶ BTU
2	0		57	.00002	
3	0		58	0	
4	0		59	.00036	
5	0		60	.00017	
6	0		61	.00519	
7	0		62	.00263	
8	0		63	0	
9	0		64	.00488	
10	0		65	.00007	
11	.090000		66	.00913	
12	0		67	.00041	
13	0		68	.00022	
14	.00005		69	.00022	
15	.00089		70	0	
16	0		71	0	
17	.00035		72	.01180	
18	.00578		73	.00734	
19	.00094		74	.00039	
20	.00277		75	0	
21	0	1967 \$/10 ⁶ BTU	76	0	
22	0		77	.00839	
23	0		78	0	
24	0		79	.00760	
25	.00007		80	.00027	
26	.00017		81	.00410	
27	.00002		82	.00043	
28	.00010		83	.00125	
29	0		84	0	
30	0		85	0	
31	0		86	.00573	
32	0		87	.00002	
33	0		88	.00021	
34	0		89	.02813	
35	.12700		90	0	
36	.00005		91	.00332	
37	.00036		92	.00391	
38	.00007		93	.00015	
39	.00043		94	.00022	
40	.00070		95	0	
41	.00102		96	.01611	
42	0		97	0	
43	.00025		98	.00937	
44	0		99	.05340	
45	.00002		100	.05229	
46	0		101	.01538	
47	.00661		102	.00532	
48	.00063		103	.08337	
49	.00411		104	.01039	
50	.56070		105	0	
51	.00051		106	.00302	
52	.00092		107	.02413	
53	0		108	.00193	
54	0		109	.01857	
55	0		110	.00732	

Appendix III (cont'd.)

1985 Coal Combined Cycle Electric Coefficients

BNL 110	A-MATRIX COEFFICIENTS		BNL 110	A-MATRIX COEFFICIENTS	
1	2.10872	BTU/BTU	56	.00528	1967 \$/10 ⁶ BTU
2	0		57	.00002	
3	0		58	0	
4	0		59	.00039	
5	0		60	.00029	
6	0		61	.00546	
7	0		62	.00327	
8	.14837		63	.00041	
9	0		64	0	
10	0		65	.00007	
11	0		66	.00541	
12	0		67	.00041	
13	0		68	.00022	
14	.00005		69	.00022	
15	.00089		70	.00008	
16	0		71	.00015	
17	.00035		72	.00043	
18	.00578		73	.00315	
19	.00094		74	.00039	
20	.00277		75	0	
21	0	1967 \$/10 ⁶ BTU	76	0	
22	0		77	.00274	
23	0		78	0	
24	0		79	.00766	
25	.00007		80	.00027	
26	.00017		81	0	
27	.00002		82	.00043	
28	.00010		83	.00128	
29	0		84	0	
30	0		85	0	
31	0		86	.00088	
32	0		87	.00004	
33	0		88	.00025	
34	0		89	.02136	
35	.18863		90	0	
36	.00005		91	.00096	
37	.00036		92	.00304	
38	.00007		93	.00002	
39	.00060		94	.00012	
40	.00072		95	0	
41	.00139		96	.01780	
42	.00003		97	0	
43	.00029		98	.01328	
44	0		99	.05543	
45	.00002		100	.04931	
46	0		101	.01652	
47	.00813		102	.00331	
48	.00092		103	.07370	
49	.00365		104	.01040	
50	.00761		105	0	
51	.00051		106	.00123	
52	.00614		107	.02391	
53	.00019		108	.00193	
54	0		109	.02117	
55	.00001		110	.00405	

Appendix III (cont'd.)

1985 Solvent Refined Coal

BNL 110	A MATRIX COEFFICIENT		BNL 110	A MATRIX COEFFICIENT	
1	1.697000	BTU/BTU	56	0	1967 \$/10 ⁶ BTU
2	0		57	0	
3	0		58	0	
4	0		59	0	
5	0		60	.000662	
6	0		61	0	
7	0		62	0	
8	0		63	0	
9	0		64	.004507	
10	0		65	0	
11	0		66	.002775	
12	0		67	.001177	
13	0		68	0	
14	.000030		69	.000306	
15	.000006		70	.000720	
16	.058068		71	0	
17	.000004		72	0	
18	.000110		73	.005373	
19	.000136		74	0	
20	.002191		75	0	
21	0	1967 \$/10 ⁶ BTU	76	0	
22	0		77	.000039	
23	0		78	0	
24	0		79	.002359	
25	0		80	0	
26	0		81	0	
27	0		82	0	
28	0		83	0	
29	0		84	0	
30	0		85	0	
31	0		86	.001414	
32	0		87	0	
33	0		88	0	
34	0		89	.000146	
35	.004824		90	0	
36	0		91	.000083	
37	0		92	.000146	
38	0		93	.000004	
39	0		94	.000037	
40	0		95	0	
41	0		96	0	
42	0		97	0	
43	0		98	.002193	
44	0		99	.001842	
45	0		100	0	
46	0		101	0	
47	0		102	.000155	
48	0		103	.003606	
49	0		104	0	
50	.000503		105	0	
51	0		106	0	
52	0		107	0	
53	0		108	0	
54	0		109	0	
55	0		110	.000401	

Appendix III (cont'd.)

1967 Fossil Electric, Light Water Reactor Electric
and Hydroelectric Coefficients

BNL 110	FOSSIL	NUCLEAR LWR	HYDRO- ELECTRIC	BNL 110	FOSSIL	NUCLEAR LWR	HYDRO- ELECTRIC
BTU/BTU				1967 \$/10 ⁶ BTU			
1	2.12470	0	0	56	.00504	.00504	.00504
2	0	0	0	57	.00002	.00002	.00002
3	0	0	0	58	0	0	0
4	0	0	0	59	.00036	.00036	.00036
5	0	0	0	60	.00017	.00017	.00017
6	.27886	0	0	61	.00519	.00519	.00519
7	.84551	0	0	62	.00263	.00263	.00263
8	0	0	0	63	0	0	0
9	.09800	0	0	64	.00391	.00391	.00391
10	0	.09802	0	65	.00007	.00007	.00007
11	0	0	0	66	.00423	.00804	.00447
12	0	0	.08731	67	.00041	.00041	.00041
13	0	0	0	68	.00022	.00022	.00022
14	.00005	.00005	.00005	69	.00022	.00022	.00022
15	.00089	.00089	.00089	70	0	0	0
16	0	0	0	71	0	0	0
17	.00035	.00035	.00035	72	0	0	0
18	.00579	.00579	.00579	73	.00661	.00661	.00661
19	.00094	.00094	.00094	74	.00039	.00039	.00039
20	.00277	.00277	.00277	75	0	0	0
21	0	0	0	76	0	0	0
22	0	0	0	77	.00976	.00721	.00976
23	0	0	0	78	0	0	0
24	0	0	0	79	.00760	.00760	.00760
25	.00007	.00007	.00007	80	.00027	.00027	.00027
26	.00017	.00017	.00017	81	.00260	.00260	.00260
27	.00002	.00002	.00002	82	.00048	.00048	.00047
28	.00010	.00010	.00010	83	.00133	.00133	.00133
29	0	0	0	84	0	0	0
30	0	0	0	85	0	0	0
31	0	0	0	86	.00030	.00470	.00037
32	0	0	0	87	.00002	.00002	.00002
33	0	0	0	88	.00021	.00021	.00021
34	0	0	0	89	.13214	.02682	.01972
36	.22873	.21337	.15766	90	0	0	0
36	.00005	.00005	.00005	91	.03739	.00295	.00092
37	.00036	.00036	.00036	92	.01707	.00376	.00294
38	.00007	.00007	.00007	93	.00011	.00012	.00002
39	.00043	.00043	.00043	94	.00042	.00020	.00010
40	.00070	.00070	.00070	95	0	0	0
41	.00154	.00229	.00154	96	.01587	.01583	.01564
42	0	0	0	97	0	0	0
43	.00025	.00025	.00025	98	.00929	.00337	.00069
44	0	0	0	99	.04464	.05094	.04153
45	.00002	.00002	.00002	100	.04907	.04907	.04907
46	0	0	0	101	.01527	.01527	.01434
47	.00661	.00661	.00661	102	.00483	.00483	.00483
48	.00063	.00063	.00063	103	.07953	.07953	.07953
49	.00379	.00379	.00379	104	.01033	.01033	.01033
50	.00764	.49488	.00752	105	0	0	0
51	.00051	.00051	.00051	106	.00271	.00271	.00271
52	.00134	.00722	.00134	107	.02408	.02408	.02408
53	.00014	.00014	.00014	108	.00193	.00193	.00193
54	0	0	0	109	.01772	.01830	.01789
55	0	0	0	110	.00350	.00575	.00329

APPENDIX IV

BESOM DESCRIPTION

Modeling Techniques

Linear programming. Given demands, resource availabilities, and technologies available, the model calculates the optimal supply/demand configuration that minimizes a quantifiable objective (usually total annualized system cost, excluding or including end-use devices). For each demand, a set of perfectly substitutable fuels is specified along with maximum and/or minimum penetration levels. Supply curve data are available for all nonrenewable resources, and a stepwise demand elasticity representation is being implemented as an optional feature.

System Described

The energy system of any nation or region with definable boundaries can be examined. The model has a comprehensive technological structure which includes (i) all alternative energy resources and both electric and nonelectric demands and (ii) the full feasible range of interfuel substitutability. The load duration characteristics of electrical demands are included. BESOM may be used in either a simulation mode or an optimization mode. Within an optimization mode, BESOM provides the optimal supply/demand configuration and the resulting quantifiable impacts, such as costs or environmental impacts which are determined by the market and technological assumptions. Within a simulation mode, BESOM can be used to determine some of the environmental, cost, and economic impacts of specific supply/demand configurations. In addition, the model can be used to rank technologies in a simulation mode.

Input Data

The input information required for the model can be broken into six general categories: (i) supply and demand efficiencies; (ii) costs; (iii) environmental impact factors; (iv) resource availabilities; (v) basic energy demands; and (vi) market penetrations.

The supply efficiencies, used to relate intermediate energy forms to primary resources, include a refining efficiency, electric conversion efficiency, transmission and distribution efficiency, and synthetic fuel-manufacturing efficiency. The refining efficiency represents a combined extraction, cleaning, and transportation efficiency. In addition, effective end-use demand efficiencies must be specified for each utilizing device.

The costs needed in BESOM include plant capital costs, operation and maintenance costs, transmission and distribution costs, resource costs, and end-use device costs. Capital recovery costs are associated with each individual electric supply category and end-use device. Also specified is a maximum utilization factor.

Environmental impacts are associated with each of the links that form the various fuel trajectories from primary resource supply to end use. The total impacts for each activity are calculated and summed up along each of the trajectories.

Market penetration equations limit the technology implementation levels.

Any linear objective function may be optimized; total system cost has been the most widely used objective function.

Output Data

A BESOM run provides the following information about the energy system being examined: (i) activity levels for the intermediate energy forms associated with the reference energy system trajectories; (ii) total resource use for each resource category and fuel type; (iii) the capacities and load factors for the electrical generating plants; (iv) environmental effects, totaled over all supply-demand trajectories; (v) the reduced costs and marginal values, of the variables and constraints, and the values of the objective functions and accounting rows.

Observations

The linearity of the objective function and the inelasticity of the demands are two oversimplifications of the model. However, the model's unified framework is particularly well suited to energy technology assessment and policy analysis since it emphasizes technological, economic, and environmental factors. The combination of BESOM with the BNL expanded IO model and the DRI macroeconomic model provides the means for a comprehensive analysis of the energy-economic interactions.

APPENDIX V

BESOM LP Structure

The model is formulated about the classical transportation problem of determining the optimal routing of a product, in this case an intermediate energy form, from a set of n supply nodes to m demand nodes where a cost and a set of environmental impacts are identified for a unit of energy passing over each of the $n \times m$ possible paths. The typical linear programming representation of the transportation problem is modified by the inclusion of efficiency coefficients in the supply and demand constraints and is augmented by additional constraint equations reflecting the environmental factors as well as certain technical features of the energy system.

The n supply nodes and m demand nodes can include all supply and demand categories. To provide a feasible path between a supply and demand category, both a supply and utilizing technology must be identified. For a given path, j , a resource S_u is converted to intermediate energy form, Z_j , at an efficiency, e_{uj} . In turn, the intermediate energy form is used to satisfy demand D_v at an efficiency d_{vj} . Each intermediate energy form contributes to a set of air pollutants B_w in accordance with emission coefficients, f_{wj} . Additional constraints G_y are placed on certain plant capacities and on electrical peaking and balance requirements. A cost c_j is also defined per unit of intermediate energy form.

In the model the intermediate energy form is defined at the point just before end-use. Intermediate energy forms include transmitted and distributed electricity, gasoline in an automobile, oil in a home oil tank, for example. The supply efficiency is calculated by multiplying to-

gether all the supply efficiencies on a path from the resource to the intermediate energy form; similarly the demand efficiency is calculated by multiplying together all the demand.

A representation of the model with a cost-minimizing objective function follows:

$$\begin{aligned} \text{Minimize: } & \sum_{j=1}^P C_j Z_j . \\ \text{Subject to: } & \sum_j \frac{1}{e_{uj}} Z_j \leq S_u \quad u = 1, n , \\ & \sum_j d_{vj} Z_j = D_v \quad v = 1, m , \\ & \sum_j f_{wj} Z_j \leq B_w \quad w = 1, r , \\ & \sum_j g_{yj} Z_j \leq G_y \quad y = 1, n . \end{aligned}$$

The coefficients of the objective function in the model can represent the dollar cost of supply and utilizing devices and can include externalities that are quantifiable in dollar costs. Objectives for the energy system may also be expressed in the model as constraints on certain environmental effects in a cost-minimizing solution. The coefficients in the objective function reflect the capital cost of the facilities used in the energy supply system as well as fuel and other operating costs. If social costs or other externalities can be quantified, these can also be included.

The optimization process generates interfuel substitution in specific end uses on the basis of the cost of supplying and the efficiency of utilizing Btu's from alternative supply sources to each end use. As new technologies are introduced, or as the fuel costs change, the model is ca-

Appendix VI

BESOM Variable Listing

I. CLASS and MEMBERS of the Class

- CO Cogeneration Plants
 - ST Steam Topping Cycle
 - GT Gas Turbine Topping Cycle
- CS Central Station Electric
 - 01 Coal Steam
 - 02 Coal Combined Cycle
 - 03 Oil Steam
 - 04 Oil Combined Cycle
 - 05 Gas Turbine
 - 06 Gas Steam
 - 08 LWR
 - 09 LMFBR
 - 10 HTGR
 - 11 Hydroelectric
 - 12 Geothermal
 - 13 Solar Electric
 - 14 Pumped Storage
- D End-Use Devices
 - T Conventional Technology
 - H Heat Pump
 - S Steam Topping System
 - G Gas Topping System
- DD Decentralized Devices
 - TE Total Energy System
 - FC Fuel Cell
- DM
 - 01 Base Load Electric
 - 02 INTMD Load Electric
 - 03 Peak Load Electric
 - 04 Storage + Synthetics

Appendix VI (cont'd.)

I. CLASS and MEMBERS of the Class (cont)

DM (continued)

05 L.F. 0.02

06 L.F. 0.05

07 Converted Resources

08 Thermal Low Temp.

09 Process Heat Med. Temp.

10 Thermal High Temp.

11 Iron Ore Reduction

12 Petrochemicals

13

14 Space Heat

15 Byproduct Heat

16 Air Conditioning

17 Water Heat

18

19 Air Transport

20 Truck, Bus, Diesel Rail, Ship

21 Electric Rail

22 Auto

- EL Electricity Gen Plants

(CS)

(DD)

- IEF

ELE Electricity

OIL Oil

GAS Gas

COA Coal

HEA Heat

MET Methanol

HYD Hydrogen

SOL Solar Direct

GEO Geothermal

NUC Nuclear

LBG Low Btu Gas

Appendix VI (cont'd.)

I. CLASS and MEMBERS of the Class (cont)

- RS Resources
- 16 Domestic Crude
- 17 Imported Crude
- 18 Shale Crude
- 19 Domestic Natural Gas
- 22 Underground Coal
- 23 Stripmined Coal
- 29 Geothermal
- 30 Solar
- 31 Imported Natural Gas
- 32 Hydropower
- 33 Uranium
- 34 Imported Residual
- 36 Woods and Wastes
- 37 Biomass

APPENDIX VII

Operational Use of the Reduced Form I-O/LP Model

The following data bases and exogenously specified parameters are required in order to make a reduced form run without the capital investment or balance of payments subprograms:

1. Input-output A matrix of coefficients of production, 110 x 110 order, in constant 1967 dollars. Coefficients do not have to be present in the first 20 rows since they are calculated from an LP solution.

2. GNP vector of final demand, 110 order, in constant 1967 dollars. A single number for each sector will suffice, or they can be subdivided into a maximum of 11 components. Entries for the first 20 sectors are expressed in 10^{15} Btu, and in 10^6 constant 1967 dollars for the remaining 90 sectors.

3. LP data base with any of the following types of data presentation as needed to specify the particular scenario being analyzed:

- a. Modifications to LP right-hand-side constraints for particular scenario being run. RHS's are only needed for the LP equations identified with an "O" in the "T" column of an equation listing.

- b. Specification of desired LP equality constraints for particular scenario being run.

- c. Modifications to standard set of LP "blocked variables."

- d. Transmission/distribution efficiency of electricity, usually 0.91.

- e. Pipeline gas transmission efficiency, usually 0.948.

To add the capital investment subprogram, the following data must also be specified:

1. Capital/output ratios for all sectors except 13 to 20 with units of 1967 dollars/ 10^6 Btu for sectors 1 to 12 and 1967 dollars/1967 dollars for sectors 21 to 110.

2. Annual replacement rates for all sectors except 13 to 20, to account for replacement of worn-out and obsolete capital stock.

3. An historical (1967 or other year) 110-order vector of total output from each sector except 13 to 20 - for runs up to the year 1985. A 1985 110-order vector of total outputs - for year 2000 runs.

4. The number of years between the historical X vector and the planning year being analyzed.

5. A disaggregated set of final demands, with personal consumption expenditures, gross private fixed-capital formation, exports, and competitive imports broken out, at a minimum, for all sectors except 13 to 20.

To add the balance of payments subprogram the following data must also be specified:

a. Price of imported crude oil, refined oil imports and imported gas in Scenario I, 1974 \$/bbl.

b. Price of imported crude oil in Scenario II, 1974 \$/bbl.

c. Crude and refined oil imports and natural gas imports from Scenario I final solution, 10^{15} Btu.

d. Fraction of petrodollars going to direct U.S. exports.

e. Fraction of petrodollars going to foreign exchange market, thus affecting exchange rate and net U.S. exports.