December 1985

ORAU--98000434

UNCERTAINTY IN FUTURE GLOBAL ENERGY USE AND
FOSSIL FUEL CO₂ EMISSIONS 1975 to 2075

APPENDICES A - B

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APPENDIX A: MONTE CARLO DATA SET

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MONTE CARLO DATA SET

The attached data sheets give the distribution for input variables used in Monte Carlo analysis of the IEA/ORAU Global Energy, CO₂ Model. The data sheets include a discussion of data sources, bibliographic sources, and other considerations used in developing the particular data format and values for distributions. While the parameters have measured or estimated values, few estimates of future values found in the literature include useful estimates of uncertainty associated with the estimated value. Thus, in general, subjective evaluation of distributions was required.

As much detail as possible about how distributions are related to published estimates is given but in most cases it was necessary to make a significant leap from available "data" to the quantified distribution. Thus, this data set serves as a starting point. The distributions are meant to be roughly accurate and to the degree that uncertainty exists about the form and value of distributions, we have tended to opt for wider bounds. This seems justified given the observed tendency for researchers to express too much confidence in their estimates. In addition, we have spent proportionately less effort on variables suspected to be of less importance as a result of sensitivity analysis. Thus, this set serves as a basis to establish rough measures of uncertainty in outputs (e.g., CO₂ emissions) and, appropriately interpreted, begin to attribute uncertainty to various subfactors.

OUTPUT VARIABLES FOR MONTE CARLO ANALYSIS*

<u>No.</u>	<u>Variable Name</u>	<u>Definition</u>
1	CO2M; M = 1, ..., 5	Global Carbon Emissions, 1975-2075
1	EDM; M = 1, ..., 5	Global Primary Energy, 1975-2075
1	EDRM; M = 1, ..., 5	Global Consumption of Refinable Fuels, 1975-2075
1	EFM; M = 1, ..., 5	Global Final Energy Consumption, 1975-2075
1	GNPFLM; M = 1, ..., 5 L = 10	Global Final GNP, 1975-2075
1	ZLXM; M = 1, ..., 5 L = 10	Global Population, 1975-2075
3	PIM; M = 1, ..., 5 I = 1, 2, 3	World Price of Fossil Fuels, 1975-2075, 1=oil, 2=gas, 3=coal
2	PUILM; M = 1, ..., 5 L = 1, I = 4, 5	Busbar Electricity Costs from Nuclear and Solar in the U.S., 1975-2075 4 = nuclear, 5 = solar
1	ESUM; M = 1, ..., 5	Global Electricity Output, 1975-2075
2	ESI2M; M = 1, ..., 5 I = 1, 3	Global Shale Oil and Biomass Production, 1975-2075 1=shale oil, 3=biomass
3	ESI1M; M = 1, ..., 5 I = 1, 2, 3	Global Conventional Fossil Fuels Production, 1975-2075, 1=oil, 2=gas, 3=coal
2	ESIM; M = 1, ..., 5 I = 4, 5	Global Primary Nuclear and Solar Production, 1975-2075, 4=nuclear, 5=solar

*M denotes time periods, 1=1975, 2=2000, 3=2075, 4=2050, 5=2075.

L denotes regions, L=10 is the total over regions 1-9.

I denotes fuel type.

INPUT VARIABLES FOR MONTE CARLO ANALYSIS: SUMMARY

<u>General Category</u>	<u>Number</u>	<u>Specific Variables</u>
Population	3	ZL (3 aggregated regions)
Income Elasticity	3	RYKK, RYLT (3 regions)
GNP Feedback	3	RYL (3 regions)
Fuel Substitution	1	RPJK, RPJ
Elec. Generation Subst.	1	RUI
Aggregate Price Elasticity	1	RPKK, RPK
Exogenous Energy Efficiency	1	TKL
Labor Productivity	2	PROL (2 regions)
Conventional Oil	4	RIGISL, CIGIS, RIL (3 regions)
Coal Supply	5	RIGISL, CIGIS, RIL, STISL, VISL
Unconventional Oil	5	RIGISL, CIGIS, RIL, STISL, VISL, Cost Scale
Natural Gas Supply	2	RIGISL, CIGIS, RIL
Nuclear	4	RIGISL, CIGIS, VISL, STISL, Cost Scale
Synfuels	2	HCILT2, GCI
Solar/Renewables	2	CSLT, CIGIS
Electricity From Coal	1	HUIL
Biomass	1	Cost Scale
Hydro	<u>1</u>	RIGISL
Total	42	

INPUT ASSUMPTION

Price Induced Interfuel Substitution in End-Use

NUMBER OF MONTE CARLO VARIABLES

1

VARIABLES INVOLVED

RPJK, RPJ

DATA FORMAT FOR MONTE CARLO ANALYSIS

RPJK and RPJ are parameters of the logit equation which control interfuel substitution. However, the logit equation determines the share of a fuel in the market (not the amount of fuel directly) and one parameter determines four own-share and six cross-share elasticities. Moreover, as used in the model, the logit equation refers to energy service prices and service shares. Thus, the parameter is not directly a fuel elasticity measure. It can be set to determine any one of the 10 own or cross elasticities but in doing so the targets for the other nine are only coincidentally met. Furthermore, since conventional price elasticities refer to changes in quantities not changes in shares, a conventional own fuel or cross fuel elasticity includes a changing share effect and a conservation effect. Thus, to meet a target set as a conventional elasticity the logit parameter and the aggregate price elasticity value must be jointly consistent with the target. For example, assuming a high aggregate elasticity may imply a positive value for the logit parameter to meet a low target for an own price elasticity. The positive logit parameter would imply that energy fuels were complements rather than substitutes which is a counter-

intuitive result. Thus, we select the logit parameter directly, restricting it to be negative and assuring that fuels are substitutes for one another.

INTEGRATION WITH MODEL SPECIFICATION

Values for RPJK and RPJ are determined as a fixed proportion of the single Monte Carlo selection.

POSSIBLE CORRELATION WITH OTHER VARIABLES

Among RPJ's

The selection of a single value on which sectoral and regional values are based implies perfect correlation among regional/sectoral substitution potentials.

With Other Variables

A possible correlation with RUI exists. See the discussion under the RUI variable listing. We do not see any obvious correlation with other variables.

BIBLIOGRAPHIC SOURCES

Same as for the aggregate price elasticity parameter.

Also

Brian Sullivan and Donna Siemon, "Interfuel Substitution--Upper Bound Estimates," Energy Journal, vol. 2, no. 2 (April 1981).

EXPERTS

Same as for the aggregate price elasticity parameter.

DISTRIBUTIONS

	Percentile				
	<u>3</u>	<u>16.5</u>	<u>50</u>	<u>83.5</u>	<u>97</u>
Logit Parameter	-.4	-1.5	-3.00	-5.0	-7.5

See the worksheet for a discussion of these values.

DISAGGREGATION TO MODEL REGIONS

<u>All OECD Regions</u>	<u>Sector (RPJK)</u>	<u>Multiplicative Factor</u>
	Residential/Commercial	1.0
	Industrial	1.0
	Transport	4.3
 All Non OECD Regions		
	Aggregate Sector (RPJ)	.83

 WORKSHEET

The logit share equation for fuel i is given as

$$S_i = \frac{b_i PS_i^{r_s}}{\sum_j b_j PS_j^{r_s}}$$

where S_i is the share of fuel i , PS_j is the price of energy services using fuel j , $j = 1, 2, \dots, i, \dots, n$, r_s is the elasticity control parameter, and b_j is a scale parameter.

The aggregate energy price equation is given as

$$E = P^r P \cdot X^r Y \cdot \text{Pop}$$

where E is the aggregate energy amount, P is the aggregate price of energy, X is income, Pop is population, r_p is the aggregate price elasticity, and r_y the aggregate income elasticity.

Furthermore,

$$P = \sum_j S_j P_j$$

and

$$PS_j = P_j \cdot g_{jk} + h_{jk}$$

(Note: The model specifies a demand for aggregate energy services rather than aggregate secondary energy, however, the data, for compatibility with the energy elasticity literature, takes a secondary energy elasticity and internally converts it to a service elasticity.)

where P_j is the secondary fuel price of fuel j , g_{jk} is the efficiency with which it is used in producing service k and h_{jk} are non-fuel costs of the service. From these it is possible to calculate the own price share

$$\epsilon S_j = r_p S_j + r_s (1 - S_j).$$

This equation demonstrates the dependence of the own price elasticity of the fuel share on the logit parameter (r_s), the aggregate elasticity (r_p), and the share the particular fuel has in the market. The secondary fuel elasticity (ϵ_j) is related to the above expression. For fuel 1 it is

$$\epsilon_1 = r_p S_1 + r_s \left(\frac{P_1}{PS_1} \right) g_{1k} (1 - S_1)$$

As one can see, the elasticity now depends on the ratio of the fuel price to the service price. Since $(P_1/PS_1) g_{1k} < 1$ (if $h_{1k} > 0$), $\epsilon_1 < \epsilon S_1$.

The above equation allows us to calculate secondary fuel elasticities from the logit parameter providing we specify values for other variables. First, suppose the aggregate elasticity (r_p) is -0.7 and the typical fuel share is $.25$ ($1/4$ of the market in a four fuel market). Further, $P_1 = 3.36$ (1975 dollars per GJ), $g_{1k} = 2.00$ and $h_{1k} = 2.1$ (1975 dollars). Given these assumptions the median logit parameter value (-3.0) implies an own price elasticity of -1.89 , the 3 percentile

logit parameter value (-.4) implies an own price elasticity of -.40, and the 97 percentile value (-13.00) gives an own price elasticity of -7.60.

The above examples refer to very specific cases. Depending on the actual fuel share, the aggregate price elasticity, and the fuel price/service price ratio the elasticities will change. For example, taking the 3 percentile logit parameter (-.40), suppose the aggregate elasticity is -.05 rather than -.7; the own price elasticity of the fuel described above is then -.24 rather than -.4. Again taking median elasticities, now suppose the fuel share were .6 rather than .25; the own price elasticity becomes -1.33 rather than -1.89. Finally, suppose the secondary fuel price doubles while other service costs remain unchanged, then the own price elasticity becomes -2.12.

INPUT ASSUMPTION

Energy/GNP Feedback Elasticity

NUMBER OF MONTE CARLO VARIABLES

3

VARIABLE(S) INVOLVED

RYL

DATA FORMAT FOR MONTE CARLO ANALYSIS

Data is specified for three regions: DEV = US + OECD PAC + WEUR & CAN + EUSSR, NOLDC = AFR + LA + SEASIA + ACENP, and MIDEAST.

INTEGRATION WITH MODEL SPECIFICATION

The value chosen for the aggregate region is assumed to hold for all subregions included in that region. The parameter is not time dependent.

POTENTIAL CORRELATION WITH OTHER INPUT VARIABLES

Among Regional Feedback (RYLs)

Since this highly stylized parameter is an aggregate describing basically the same theoretical links, one might posit that uncertainty in the magnitude is due to measurement error and other problems in estimating the parameter. Since these same problems exist worldwide, one might expect that if a relatively high (negative) value were true in DEV one should

expect a relatively high value in the NOLDCs, etc. In other words one might expect very high correlation. This suggests the possibility of reducing the Monte Carlo analysis to one distribution with values for other regions determined via a fixed $\pm$ value or proportion of the selected value.

With other Parameters

We do not see obvious correlation with other variables.

RYL DISTRIBUTIONS

	Percentile				
	<u>3</u>	<u>16.5</u>	<u>50</u>	<u>83.5</u>	<u>97</u>
<u>Region</u>					
DEV	-.01	-.05	-.15	-.20	-.30
NOLDC	-.05	-.10	-.20	-.30	-.40
MIDEST	-.05	0	+.05	+.10	+.20

BIBLIOGRAPHIC SOURCES

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EXPERTS

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INPUT ASSUMPTION

Income Elasticity

NUMBER OF MONTE CARLO VARIABLES

3

VARIABLES INVOLVED

RYKK, RYKLT

DATA FORMAT FOR MONTE CARLO ANALYSIS

A separate distribution is determined for $OECD = US + WEUR\&CAN + OECD$ PAC, EUSSR, and $LDC = AFR + LA + SEASIA + MIDEAST + ACENP$. The income elasticity is a partial derivative concept, implicitly holding constant such things as price changes and technological change in the efficiency of energy use. If income levels increased and more of everything were demanded in equal proportions, holding price and technology constant, then the income elasticity would be 1.0. If there is a tendency to switch to more (less) energy intensive products as income increases then the income elasticity would be greater (less) than 1.0.

INTEGRATION WITH MODEL SPECIFICATION

The model specifies separate elasticities for each sector in the OECD regions. For purposes of the Monte Carlo analysis a single value is chosen for the aggregate OECD region and it is assumed to hold for each sector in each subregion.

In the LDC regions the elasticity is assumed to decline to 71 percent of its initial value by 2050 and in EUSSR it is assumed to decline to 80 percent of its initial value by 2050. This reflects the assumption that the income elasticity is initially high but declines over the course of development. As in the case of the OECD value, the chosen value for the aggregated region is assumed to hold directly in all subregions.

POSSIBLE CORRELATION WITH OTHER VARIABLES

Among RYKK

Since measurement problems and functional specification may dominate estimation of the income elasticity and resolution in one region may lead to similar resolution elsewhere, one might expect positive correlation among regions. Also, individual choice of energy using products is, to some extent, dependent on what types of products are available. Since information/transportation makes similar products available worldwide one might expect further correlation. On the other hand, different tastes may exist across regions which lead to less than perfect correlation.

Assessed Impact: Positive correlation - moderate to strong.

Among Other Variables

We don't see any other likely correlation.

BIBLIOGRAPHIC SOURCES

See Aggregate Price Elasticity: Bibliographic Sources

EXPERTS

Same as Aggregate Price Elasticity experts.

PROBABILITY DISTRIBUTION

<u>Region</u>	Percentile				
	<u>3</u>	<u>16.5</u>	<u>50</u>	<u>83.5</u>	<u>97</u>
OECD	.20	.70	1.0	1.20	1.40
EUSSR	.20	.80	1.25	1.45	1.80
LDC	.50	.80	1.40	1.9	2.20

INPUT ASSUMPTION

Fuel Substitution for Electricity Generation

NUMBER OF MONTE CARLO VARIABLES

1

VARIABLES INVOLVED

RUI

DATA FORMAT FOR MONTE CARLO ANALYSIS

The RUI's are parameters of the logit equation describing fuel substitution in electric power production. They control long-term price elasticities. (See the discussion of Interfuel Substitution in End-Use which also is based on the logit function.) A single distribution, applicable to all regions over all time is required. Once a value is selected, it is invariant across regions and over time.

INTEGRATION WITH MODEL SPECIFICATION

The data format is entirely consistent with the model structure, i.e., the model currently allows no time or regional variation in the parameter.

POSSIBLE CORRELATION WITH OTHER VARIABLES

RPJK, RPJ

One might argue that fuel substitution in the general economy (RPJK, PJ) is correlated with sectoral rates, as in fact we do in linking

RPJK's. Thus, one might argue that RPJK's and RUI's should be correlated. However, this argument does not seem particularly compelling. The electric utility industry represents a very specialized use of energy--largely to raise steam in boilers. This is a major activity in the industrial sector but industrial boilers are much smaller than electric utility boilers and so could be argued to be a much different type of technology because of the scale aspect. Moreover, something less than infinite elasticities for electric utilities in the long-run are justifiable because of the fact that the logit equation captures intraregional variation in prices not explicitly modeled, whereas when applied to end-use energy consumption less the infinite elasticities may largely result from the particular type of energy service required and the different characteristics of fuels which make them more or less desirable for such an application. In short, the geographical distribution of prices affect electric generation substitution, while the distribution of technologies affects end-use scenarios. Thus, the likely correlation seems negligible.

Assessed Impact: negligible.

Bibliographic References

Little literature exists here. One can observe that cost is probably the major factor in deciding among the type of plant built for baseload generation. But the data needed to estimate long-term elasticities, 40 plus years, and the need to control for a host of technology developments over the period make normal estimation from historical data extremely difficult.

Experts

See above.

DISTRIBUTION

	Percentile				
	<u>3</u>	<u>16.5</u>	<u>50</u>	<u>83.5</u>	<u>97</u>
Value	-.4	-1.0	-3.0	-7.0	-12.00

INPUT ASSUMPTION

Aggregate Energy Price Elasticity

NUMBER OF MONTE CARLO VARIABLES

1

VARIABLES INVOLVED

RPKK, RPK

DATA FORMAT FOR MONTE CARLO ANALYSIS

Data is specified as a single distribution of elasticities (X^VQ/X^VP) for secondary energy demand.

INTEGRATION WITH MODEL SPECIFICATION

The model internally converts the secondary fuel elasticities to service elasticities, given costs of services as specified in the model, to be consistent with 1975 price/quantity data. The model separately specifies sector elasticities (three sectors for OECD regions, one sector for Developing and Centrally Planned Regions). No regional variation within these two groups is possible in the current version of the model. Given a Monte Carlo selection, all sector elasticities are calculated as a fixed proportion of the selected value. This implicitly assumes perfect correlation between sector and regional elasticities. Since the uncertainty seems to spring from such factors as functional specification,

data accuracy, possible changing relationships over time, etc., which if resolvable would probably be similarly resolved across regions and sectors, this assumption seems justified.

POTENTIAL CORRELATION WITH OTHER INPUT VARIABLES

There does not appear to be any obvious correlations with other variables.

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EXPERTS

<u>Experts</u>	<u>Institution</u>
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See EMF Working Group Participants List.

DISTRIBUTIONS

	Percentile				
	3	16.5	50	83.5	97
Elasticity Value	-0.05	-0.2	-0.7	-1.0	-1.3

DISAGGREGATION TO MODEL REGIONS

The selected elasticity value is assumed to hold for all economy sectors and all regions.

INPUT ASSUMPTION

Exogenous Energy Efficiency

NUMBER OF MONTE CARLO VARIABLES

1

VARIABLES INVOLVED

TKL

DATA FORMAT FOR MONTE CARLO ANALYSIS

Data is specified as a single distribution of annual rates of increase in output per unit energy used. This is a partial concept, i.e., efficiency improvements due to price changes or changed energy use due to changes in income are not included. This parameter is non-zero if one believes that technological change (not induced by fuel price changes) makes it possible to produce more with less energy, if public policy dictates conservation measures beyond price induced measures, or if there are exogenous shifts in consumer preferences (not price or income induced).

INTEGRATION WITH MODEL SPECIFICATION

Separate rates are specified for each of the nine regions and each of three sectors in the three OECD regions. However, for purposes of the Monte Carlo analysis only one random choice is made and all regional and sectoral rates are assumed to equal this rate.

POSSIBLE CORRELATION WITH OTHER VARIABLES

Among TKL

The proposed Monte Carlo method implies perfect correlation among TKL. High correlation may be justified by arguing that technological change is not bound by international borders given communication, trade, transport, etc. Perfect correlation is probably somewhat extreme but is further justified by the need to keep the number of variables manageable.

Among the Variables

Correlation with labor productivity is discussed in that section.

DISTRIBUTIONS

	Percentile				
Value (%/year)	3	16.5	50	83.5	97
	0.0	.002	.01	.017	.03

BIBLIOGRAPHIC SOURCES

The literature has not always clearly separated technological change from price or income induced changes in energy use per unit of output. To the extent it has the literature is the same as the price and income elasticity literature. Also see Reilly et al., 1983a, chapter 5.

EXPERTS

See above.

INPUT ASSUMPTION

Population

NUMBER OF MONTE CARLO VARIABLES

3

VARIABLES INVOLVED

ZLM

DATA FORMAT FOR MONTE CARLO ANALYSIS

To reduce the number of variables, the nine regions are aggregated to three: DEV = US + OECD PAC + WEUR & CAN + EUSSR, ACENP, LDC = AFR + LA + SEASIA + MIDEAST. Population size distributions are determined for 2000, 2025, 2050, 2075, 2100.

INTEGRATION WITH MODEL SPECIFICATION

To further reduce the number of Monte Carlo variables, a single randomly selected population size for each region is made (i.e., a selection for only one year is made). It is then assumed that the same percentile value choice is made for all other years: e.g., suppose two billion is chosen for China for year 2025 and that this represents the 78th percentile distribution. The 78th percentile population values are then automatically chosen for all other years. This process allows the path of future population growth to be fully determined by the data, e.g., no particular functional form, e.g., like exponential growth, is imposed. It also assures that, given consistency in the data, general continuity is

maintained. For example, if population size were randomly chosen for each year it would be possible that, e.g., a high value would be chosen for 2000 and a low value for 2025 such that unreasonable negative population growth was obtained or perhaps more likely that a low value chosen for 2000 and a high value chosen for 2025 would imply a return to unreasonably high fertility rates over the period. Once the three aggregated regional populations are determined, the subregional populations are determined as fixed shares of the region.

POTENTIAL CORRELATIONS WITH OTHER INPUT VARIABLES

Among Regional Populations (ZLM)

Some correlation may exist due to something like the possibility or success of world campaigns by organizations such as the UN for population control measures, but acceptance of such measures in one country probably is not correlated with acceptance in another country. Thus, expectations of success of such programs would have the impact of lowering the distributions but not necessarily leading to correlations among them. Thus, correlation among regions can probably be discounted.

Assessed Impact: Neutral.

Labor Productivity (PROL)

See the labor productivity brief for a discussion.

Assessed Impact:

Dev. — Neutral.

China — Negative correlation - weak.

LDCs — Negative correlation - weak to moderate.

Higher productivity is associated with lower and improved technology.

Pollution Costs of Energy Production (VISL)

Population pressure on the environment means it is less likely that dirty industries can be isolated from population centers, recreation centers, etc. Also, the population/labor force link means that a larger population implies a higher GNP which further implies a bigger scale energy industry and, presumably, more pollution and more need for controlling pollution. (This latter effect could be eliminated by directly modeling pollution cost as dependent on industry scale.) Regionally, one might expect somewhat less correlation for the LDC and China regions, given current priority on development over environment but this may change as development occurs. No basis for differentiating among nuclear, coal, solar, and shale oil appears obviously justified. However, a negligible impact for conventional oil and gas is assumed.

Assessed Impact:

Dev. — Positive correlation - moderate to strong.

China — Positive correlation - weak.

LDCs — Positive correlation - weak.

DISTRIBUTIONS

(Population in Millions)

OECD + Soviet Union + Eastern Europe

<u>Year</u>	<u>Percentile</u>				
	3	16.5	50*	83	97
1975	-	-	1,141	-	-
1981	-	-	1,200	-	-
2000	1,214	1,283	1,356	1,433	1,514
2025	1,282	1,382	1,489	1,604	1,728
2050	1,326	1,430	1,541	1,661	1,789
2075	1,280	1,415	1,564	1,728	1,909
2100	1,221	1,385	1,570	1,778	2,013

China and Communist Asia

<u>Year</u>					
	3	16.5	50*	83.5	97
1975	-	-	911	-	-
1981	-	-	1,069	-	-
2000	1,118	1,181	1,248	1,319	1,393
2025	1,291	1,391	1,499	1,615	1,739
2050	1,388	1,497	1,613	1,738	1,872
2075	1,348	1,490	1,647	1,820	2,010
2100	1,291	1,465	1,660	1,880	2,128

*Values from the 50th percentile are from Keyfitz, et al. except 2100 value is estimated. But it is little different than 2075 since stationarity is practicably established by then.

DISTRIBUTIONS (cont'd)

(Population in Millions)

LA + AFR + SEASIA

<u>Year</u>	<u>Percentile</u>				
	3	16.5	50	83.5	97
1975	-	-	1,923	-	-
1981	-	-	2,223	-	-
2000	2,948	3,114	3,288	3,471	3,664
2025	3,770	4,062	4,375	4,711	5,072
2050	4,343	4,681	5,044	5,434	5,853
2075	4,284	4,737	5,235	5,784	6,387
2100	4,123	4,676	5,300	6,003	6,796

Mid 1981 populations from "1981 World Population Data Sheet," Population Reference Bureau, Washington, D.C.

Method: Based on judgment and the material developed in Keyfitz et al. (1983).

 DISAGGREGATION TO MODEL REGIONS

<u>Region</u>	<u>Factor</u>
<u>Developed</u>	<u>1.0</u>
USA	.187
WEUR & CAN	.359
OECD PAC	.108
EUSSR	.346
<u>China and Communist Asia</u>	1.0
ACENP	1.0
<u>Developing</u>	1.0
Mideast	.046
AFR	.220
LA	.162
SEASIA	.572

Based on Reilly et al. (1983a), p. 13, population estimates for 2075.

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Leading Experts

World Bank

K. C. Zachariah and My T. Vu, Policy and Research Unit, Population, Health and Nutrition Department. Tel: 477-1234.

Harvard University

Nathan Keyfitz, Center for Population Studies, 9 Bow St., Cambridge, MA 02138. Tel: (617) 495-2021.

World Population Society

Philander Claxton, 1337 Conn. Ave., NW., Washington, D.C. Tel: 833-2440.

Bureau of the Census

Sam Baum, Chief of Center for International Research. Tel: 763-2870.

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INPUT ASSUMPTION

Labor Productivity

NUMBER OF MONTE CARLO VARIABLES

2

VARIABLES INVOLVED

PROL

DATA FORMAT FOR MONTE CARLO ANALYSIS

To reduce the number of variables, regions are aggregated as follows:
DEV = US + WEUR & CAN + OECD PAC + EUSSR and LDC/ACENP = ACENP + AFR + LA +
SEASIA + MIDEAST. A single distribution of growth rates for each region is
assumed, implying constant growth over the full period from 1975 to 2100.

INTEGRATION WITH MODEL SPECIFICATION

Subregional productivity growth rates are assumed to equal the
randomly chosen aggregate value. This can imply some seemingly perverse
results. Given that labor forces are growing at different rates in
subregions and initial absolute productivity levels differ there is no
simple way to assure that the aggregately specified productivity rate
actually results after applying it to subregions and then reaggregating
them. This effect can be mitigated by developing the data with this in
mind (it is an index of sorts) and by grouping (as has been done) regions
that do not have "too" different labor force growth rates and initial
productivity levels.

POTENTIAL CORRELATIONS WITH OTHER INPUT VARIABLES

Among Regional Productivity Growth Rates (PROL)

Productivity rates between the two regions are likely to be significantly correlated. Certainly, growth rates are correlated with business cycles. There may be less reason to think long-term growth is correlated. However, technological advance is a worldwide phenomena, not bound by political borders given that efficient information transfer exists; international capital markets, to the extent they are free of controls suggest a tendency for equivalent investment returns across countries (capital flows to points of highest return) and therefore similar trends in investment rates and productivity growth.

Assessed Impact: Positive correlation - strong.

Exogenous Energy Efficiency Improvement (TJKLM)

If one believes that learning/discovery is an important source of labor productivity improvement (as opposed to pure capital accumulation) and if one posits that learning/discovery has a component which is very general in nature (i.e., basic research undirected by practical concerns but percolating down to have practical impacts) then one might expect that high labor productivity growth would be correlated with big improvements in energy efficiency. That is, basic research improves labor productivity but also improves energy efficiency. Regionally, one might expect the effect to be stronger in the developed regions because productivity growth is more likely due to discovery rather than capital accumulation whereas in the developing countries the "catch-up" phenomena may be largely due to the adaptation of technologies discovered in the developed countries.

Correlation would be observed but it would be indirect via correlation between developed and developing regions' rates of labor productivity improvement.

To the extent that capital accumulation causes productivity growth, it may also cause a correlation with energy efficiency improvements since rapid capital accumulation and implied high rates of investment mean that the share of recent vintage capital (and more energy efficient capital) is growing faster than if less capital accumulation occurred. This tendency seems unlikely to vary between regions.

Assessed impact:

Dev. — Positive correlation — moderate.

LDC/China — Positive correlation — weak to moderate.

Technological Change in the Energy Producing Sector

The general learning/discovery argument applies here as above. The capital accumulation argument probably is less applicable since here one small sector of the economy (energy) is being compared to an aggregate measure (productivity) and the opportunities for investment need not be correlated except to the extent that the energy sector is a part of the economy. However, here the assumption that it is an insignificantly small part is probably justified.* However, to the extent that changes in investment ~~and~~ stimulated by changes in the supply of funds (due to changes in individuals willingness and desire to save) one might expect as a first approximation additional investment across the board. This connection may

*See Edmonds and Reilly Congressional testimony.

lead to weak correlation. For the same reasons as for TJKLM, there is likely to be less correlation in the developing than in the developed countries.

Assessed impact:

Dev. — Negative correlation* — weak

LDC/China — Negative correlation — negligible.

Population (ZLM)

Improved productivity implies higher GNP/capita. Thus, assuming that the standard, economic models of the demographic transition hold, a negative correlation between population and productivity would be expected. However, given that the developed regions have, for practical purposes, completed this transition one might expect little correlation there. In the ACENP (China) region, the demographic transition is probably further progressed than for the LDCs as a whole. So the future impact of productivity might be weaker. In both the ACENP and LDC regions, the 1960s and 1970s experiences have, perhaps, questioned the relative importance of economic factors. Cross country experience has not been very supportive of the strength of the theory and other factors—e.g., family planning programs—have appeared to have major impacts on their own.

Correlation resulting from causality flowing in the opposite direction, from population to productivity, might also be considered. An extreme characterization of one view would hold that the economic pie is fixed, adding more people (laborers) just means less to go around. Thus average productivity necessarily falls because of higher unemployment. The

*i.e., higher productivity is associated with lower cost production (improved technology).

opposite, though less frequently heard view, might be characterized as "necessity is the mother of invention;" i.e., population pressures on resources, etc., cause society to look harder for solutions and this process is so successful that one is even better off than before. The former position would lead to a negative correlation, the latter to a positive correlation between productivity and population growth.

Overall there are more reasons to expect a negative correlation and the factors suggesting a positive correlation seem relatively weak.

Assessed Impact:

Dev. — Negative correlation - negligible.

China — Negative correlation - weak to moderate.

LDCs — Negative correlation - moderate.

Pollution Cost of Resources (VISL)

Faster economic growth means larger scale industry. Increasing scale means the environment may be more seriously degraded causing imposition of control technologies. Thus, positive correlation might be expected. (This correlation could be eliminated by making pollution cost depend directly on industry scale.) In addition, the demand for a clean environment may have a societal income effect, thus as income per capita (labor productivity) in society increases more stringent controls are adopted.

An opposing effect is the general knowledge argument used above. General knowledge while increasing labor productivity may also lead to improvements in environmental control technologies and therefore lower cost (a negative correlation).

The positive correlation (higher productivity--higher pollution cost) seem to dominate in general. Regionally, one might argue for less correlation in China/LDCs because of the priority of growth over environment although this could gradually change over time. The regional perspective on the knowledge argument is the same as the discussion above under "Exogenous Energy Efficiency."

Assessed Impact:

Dev. -- Positive correlation - moderate to strong.

China/LDC -- Positive correlation - negligible.

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DISTRIBUTIONS

BASE PRODUCTIVITY RATES

	<u>Percentile</u>				
	<u>3</u>	<u>16.5</u>	<u>50</u>	<u>83.5</u>	<u>97</u>
Developed	-.005	.005	.017	.025	.040
Developing	-.01	.005	.029	.040	.055

INPUT ASSUMPTION

Conventional Oil Supply

NUMBER OF MONTE CARLO VARIABLES

4

VARIABLES INVOLVED

RIGISL, RIL

DATA FORMAT FOR MONTE CARLO ANALYSIS

A group of parameters control conventional oil supply. Two are considered important for Monte Carlo analysis. These are the resource amount and the medium run (25 year) elasticity of supply. The resource amount parameter acknowledges that relatively high grade (low cost) oil is in limited supply and as this grade is exhausted, additional conventional supplies will be more costly to produce. The medium run elasticity of supply recognizes that even if the oil exists as part of the resource, the discovery, development, and production process may prevent all of the oil from being produced in a very short time frame. Moreover, optimizing producers may have expectations about the future price of oil which cause them to hold it for later production and higher discounted profits. Thus, even though additional low cost resources might exist, price increases would be necessary to induce additional supply.

The resource data format posits five resource grades and establishes a distribution for the quantity of total oil resources in each grade. To reduce the number of Monte Carlo parameters, only one distribution is

randomly sampled and the choice of values for other grades is deterministically linked to that choice (same procedure as for population). This is somewhat unrealistic but is necessary to reduce the number of Monte Carlo variables. This also introduces a potential bias to the extent that these are not perfectly correlated (positively). In fact, if all uncertainty that existed in resource grades was due to uncertainty about what grade the oil was in rather than how much total oil there was, then the above process would give uncertainty where none existed. However, care can be taken in determining the distributions to eliminate such bias.

The elasticity parameter format is a single value selected which holds over all time. Regional elasticities are deterministically linked to this Monte Carlo variable.

INTEGRATION WITH MODEL SPECIFICATION

The resource amounts available at different costs are entered directly. The elasticity value is entered directly but needs somewhat more explanation to understand how it works. The supply function is one that becomes increasingly inelastic the more that is demanded. The entered elasticity value holds at the price/quantity combination achieved in the previous period. Thus, it is assumed that the quantity produced in the previous period can be produced in the next period at last period's price (neglecting resource exhaustion considerations which are handled separately) but any expansion beyond that level will require a price rise.

POTENTIAL CORRELATION WITH OTHER VARIABLES

Among Regional Resources

One might expect correlation. For further discussion see that for correlation among regional natural gas resources.

Assessed Impact: positive correlation - moderate

With Gas Resource and Elasticity Estimates

See discussion under natural gas.

Assessed Impact:

Resources: positive correlation - strong

Elasticities: positive correlation - strong

With Other Supply Parameters

There is little reason to expect correlation with other resource estimates. However, there may be correlation with supply elasticities given that some of the same types of factors may come into play, e.g., limits on how fast people can be trained and gain experience, expansion of support industry, infrastructure, etc.

Assessed Impact:

Resources: neutral

Elasticities: positive - strong.

DISTRIBUTIONS

Global Oil Resources Remaining

By Region and Cost Grade for Remaining Resources in Exajoules (1975)*

REGION: DEV

Grade (1975 \$/gigajoule)	Percentile				
	3	16	50	83	97
.16-.82	180	280	370	540	700
.82-3.80	500	780	1070	1540	2020
3.80-5.10	1000	1560	2130	3070	4020
3.15-7.10	850	1320	1800	2600	3400
7.10-12.30	620	980	1410	1920	2520

REGION: MIDEAST

Grade (1975 \$/gigajoule)	Percentile				
	3	16	50	83	97
.16-.82	200	300	400	700	1000
.82-3.80	860	1030	1000	1470	1741
3.80-5.10	620	750	880	1070	1260
5.10-7.10	2800	3410	3650	4610	5270
7.10-12.30	1030	1240	1460	1780	2100

REGION: LDC & ACENP

Grade (1975 \$/gigajoule)	Percentile				
	3	16	50	83	97
.16-.82	300	370	430	690	950
.82-3.80	720	880	1040	1660	2280
3.80-5.10	1280	1560	1840	2950	4050
5.10-7.10	970	1190	1410	2260	3100
7.10-12.30	730	890	1060	1700	2330

*See Worksheet for discussion/explanation. Converted to EJ from bbo assuming an average of 5813×10^6 joules per barrel of unstandardized crude oil.

25 Year Elasticity

	Percentile				
	<u>3</u>	<u>16</u>	<u>50</u>	<u>83</u>	<u>97</u>
Elasticity Value	0.0	0.3	1.0	1.5	2.0

See Worksheet

DISAGGREGATION TO MODEL REGIONS

<u>DEV</u>	<u>Fraction</u>
USA	.207
WEUR & CAN	.271
OECD PAC	.008
EUSSR	.514
	<u>1.000</u>
<u>LDC & ACENP</u>	
ACENP	.145
AFR	.419
LA	.369
SEASIA	.067
	<u>1.000</u>
MIDEST	1.000

The fractions reported above are used to disaggregate from the 3 Monte Carlo distributions to the 9 model regions for all grades. They are computed as remaining resources for each region as a fraction of the total for the combined region, e.g., USA/DEV, and based on remaining resources reported in Reilly, et al. 1983, p. 37.

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EXPERTS

Richard Heede, University of Colorado
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WORKSHEET -- OIL RESOURCES

Source for figures in this section: Richard Heede, "A World Geography of Recoverable Carbon Resources in the Context of Possible Climatic Change." Master's Thesis, Department of Geography, University of Colorado, 1983.

Amounts

(Gigatons)

<u>Region</u>	<u>Reserves (1980)</u>	<u>Remaining Recoverable Resources</u> (Including NGLs)* (Heede - p. 29)
DEV	17.7	46-98-185 (53-113-213)
MIDEST	49.6	85-120-173 (98-138-199)
LDC & ACENP	20.6	59-85-187 (68-98-215)
Deep Offshore/Antarctic	0.0	6-35-225 (7-40-259)

Economics

Heede, p. 57 reports the following economic categories and amounts due to Grenon (1980) and Desprairies (1978).

1976\$'s/bbl

	<u><5</u>	<u>5-12</u>	<u>12-20</u>	<u>Total</u>
Amount (GT)	108	78	114	300
% of total	36	26	38	100
In 1982\$ these categories are	<7.50	7.50-18	18-30...	

*Natural Gas Liquids (NGL) are assumed to be 15% of the oil estimate for high and low limits. Heede gives only a best guess for NGL.

We take Heede's best guess + NGL as the best guess for total resources or 389 GT. To divide this by grade we could assume the same shares as Heede reports for Grenon or the same amounts and add more expensive grades. Heede assumes increased average recovery rates (to 40-50 percent) and includes deep offshore and Antarctic oil which is plausible to include given 1979 price increases the Grenon/Despraires data did not foresee. Moreover Heede discusses enhanced recovery, deep offshore, and Antarctic costs as \$30-40 (1978\$s) (\$40-54 in 1982\$ or 28-36 in 1976\$s).

We assume that Heede and Grenon are consistent in quantities but that Heede adds another grade. We also assume no oil is produced below 1.50 (1982\$). In addition, we assume a still higher cost grade (\$50-100) implying further increase in the recoverable share from Heede's assumed 40-50 percent to 50-60 percent of the in-place resource at still higher prices.

Thus, we get:

	1982\$/barrel				
	1.50-7.50	7.50-18.00	18-30	30-50	50-100
Amount (GT)	108	78	114	89	78

We make the following regional gradation assumptions:

For the first grade (1.50-7.50):

(1) One-half of the reserves of the DEV and LDC + ACENP fall into the lowest cost category because the exploration and many of the development costs are sunk.

(2) We assume all remaining (after (1)) resources of the cheapest oil (totaling to 108 GT) is in the Middle East. This yields the amounts in column 1 of the next table.

...and almost certainly quite expensive oil.

For the next grade (7.50-18.00) we assume

- (1) 85 percent of Mideast oil falls in the two lowest categories--the additional 15 percent represents enhanced recovery techniques (raising recovery from roughly 40 percent to 50 percent of the oil in place).
- (2) The additional 30.6 gt estimated to fall in this category are divided between the other two regions in proportion to their total remaining resources.

For the next grade (18-30)

- (1) All of Heede's additional resources for the Middle East fall in this category.
- (2) The remaining 93.3 gt estimated to fall in this category are divided between DEV and LDC + ACENP in the same proportion as their total remaining resources.

For the next grade (30-50)

All of Heede's remaining resources fall in this category as regionally specified. Deep offshore and antarctic oil is divided equally among regions.

For the final grade (50-100)

Estimated as 10 percent of the in-place resource (assuming Heede's recoverable amounts represent 45 percent of in-place resources and also adding on past production to remaining resources for each region but excluding deep offshore and Antarctic oil).

COST

1982\$/barrel*	1.50-7.50	7.50-18.00	18-30	30-50	50-100
1975\$/barrel*	1.00-5.00	5.00-11.00	11.00-19.00	19.00-31.00	31-63
DEV	8.8	25.1	50.0	42.4	31.4
MIDEST	88.9	28.4	20.7	13.3	34.2
LDC & ACENP	10.3	24.5	43.3	33.2	24.9

*The conversion rate is $.63 \times 1982\$ = 1.0 \times 1975\$$ but converted values are rounded to the nearest dollar reflecting the approximate nature of the cost estimates.

To develop a distribution in each grade for each region we assume that Heede's regional high and low estimates represent 3 and 97 percentile limits for total resources and that the limits for each grade is proportional to the total. This is consistent with the selection process described in the Monte Carlo analysis. The 16.5 and 83.5 percentile values are taken as the point midway between the 50 percentile and the 3 and 97 percentile values.

Finally, for oil that is yet undiscovered, the above estimated costs appear too low. In particular, the cost appears to refer largely to production costs. Discovery costs are likely to be significant and other costs may be incurred beyond direct costs. Thus, we add \$2.00/GJ to the price beginning at the price point separating the second and third grades. We also move 90% of the oil in grade 1 and 17 percent of the oil in grade 2 to grade 4 in the Middle East. This adjustment accounts for the monopoly power the region holds in oil production, that is, it is unlikely to produce vast reserves of oil at cost but rather reduce production. The extreme high values (the 84th and 97th) percentiles are adjusted less

in an attempt to account for the possibility that OPEC will not use its market power or that its power is weaker than it might appear to be at the current time.

25 Year Supply Elasticity

This is a very difficult parameter to evaluate. The 50 percentile value is set at 1.00, the 3 percentile value at 0.0 and the 97 percentile value at 2.00. This allows for the possibility of no price response on the low side to a fairly elastic price response on the high side. Thus, it makes further penetration impossible or quite easy depending on the values selected. In evaluating these figures, one must remember that the hypothetical expansion rates do not include exhaustion of high grade resource impacts. These impacts are treated explicitly and separately.

INPUT ASSUMPTION

Natural Gas Supply

NUMBER OF MONTE CARLO VARIABLES

2

VARIABLES INVOLVED

RIGISL, RIL

DATA FORMAT FOR MONTE CARLO ANALYSIS

See Conventional Oil Supply. However, because of lack of data we do not specify separate regional resource distributions. Instead, regional resources are deterministically linked to the global resource estimate.

INTEGRATION WITH MODEL SPECIFICATION

See Conventional Oil Supply.

POTENTIAL CORRELATION WITH OTHER VARIABLES

Among Regional Resource Estimates

Since natural gas tends to be found in similar types of geologic formations, should new types or slightly varied types of formations prove to hold gas in one region one would probably expect to find gas in similar formations around the world. Moreover, if a specific formation proves to have more gas than expected one might expect a tendency to revise, upward, estimates of gas in similar formations across regions.

Assessed Impact: positive correlation - moderate.

With Conventional Oil Resources

Conventional wisdom argues for a common origin for natural gas and oil. Moreover, gas is frequently found in association with oil. Thus, one might expect high correlation between oil and gas resource estimates. More recently, some experts have maintained that large amounts of nonassociated gas may be abiogenic and therefore different, in origin, than oil. The existence of such resources would reduce the correlation, however, we include such sources, if they exist, in the unconventional gas supply category. Since exploration, development, and production methods are similar or in some cases one and the same (e.g., exploration for oil may lead to oil or gas discovery and gas is produced in association with oil), one might also expect supply elasticities to be highly correlated as well.

Assessed Impact:

Resources: positive correlation - strong.

Elasticities: positive correlation - strong.

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Same as Conventional Oil Supply

EXPERTS

Same as Conventional Oil Supply.

DISTRIBUTIONS

World Gas Resources (EJ)

	Percentile				
	<u>3</u>	<u>16</u>	<u>50</u>	<u>83</u>	<u>97</u>
Grade (1975\$/GJ)					
.20-1.50	2,090	3,350	4,600	5,440	11,290
1.50-2.50	860	1,380	1,900	2,250	4,660
2.50-3.60	1,590	2,550	3,500	4,140	8,590
3.60-15.00	450	730	4,000	5,180	42,450

(See Worksheet for a discussion)

Supply Elasticity

	Percentile				
	<u>3</u>	<u>16</u>	<u>50</u>	<u>83</u>	<u>97</u>
Elasticity Value	0.0	0.3	1.0	1.5	2.0

(Assumed to be the same as for oil, see oil worksheet.)

Generally showed positive correlation with

large positive correlation with

DISAGGREGATION TO MODEL REGIONS

<u>Region</u>	<u>Fraction</u>
USA	.146
WEUR & CAN	.094
OECD PAC	.015
EUSSR	.288
ACENP	.039
MIDEAST	.229
AFR	.075
LA	.080
SEASIA	<u>.035</u>
	1.00

Based on remaining resources by region reported in Reilly, et al.,
1983, p. 119.

 WORKSHEET — GAS RESOURCES

Amounts

Heede (1983), p. 30 presents the following reserve and remaining resource estimates.

(In Gigatons)

	<u>Reserves</u>	<u>Remaining Recoverable Resources</u>
DEV	34.94	106.4
MIDEST	14.11	58.6
LDC & ACENP	<u>14.66</u>	<u>60.0</u>
	64.71	225.0

*DEV = US + WEUR&CAN + OECD PAC + EUSSR

Heede's literature review suggests recent estimates falling in the range of 100 GT to 190 GT remaining resource for the world. Heede's estimate is considerably higher but he does not give much justification or explanation as to why his estimate differs. A large proportion (62%) of the gas included in his total is nonassociated gas and given the relatively little exploration for such gas in the developing countries--many are still flaring associated gas--tremendous uncertainty doubtlessly exists and current methodologies may have underestimated the amounts.

There are no estimates of the uncertainty associated with gas resource estimates. Inferences about uncertainty might be drawn from the distribution of best guesses given in the literature but this seems like it would underestimate uncertainty--particularly on the high side. Moreover, it is not possible to get much regional data so it is difficult to get measures of uncertainty for regions. We propose that the following distribution might offer a better estimate of the true uncertainty for the world.

	Percentile				
	<u>3</u>	<u>16.5</u>	<u>50</u>	<u>83.5</u>	<u>97</u>
Gigatons	100	150	200	250	500
EJ*	5,000	8,000	11,000	13,000	27,000

We then deterministically link regional resources estimates via a fixed share of the world total.

Economics

The economics of gas production are very poorly known. Almost no literature exists concerning what prices would make available the resources estimated to exist. In part, this is because associated gas is produced as a by-product of oil production and may be flared or vented, thus it is something to be disposed of rather than valued. This has changed rapidly but in some places gas remains a by-product which any positive price will fetch. However, given that the user must pay expensive transportation and distribution charges a positive price which is competitive with other fuels may not exist. Of course, the U.S. and more recently Europe and the Soviet Union produce nonassociated gas. WEC (1978) estimated that gas prices equal to \$14/bbl crude oil equivalent (1974 dollars) (or about 2.30/GJ in 1974\$ or 2.50 in 1975\$ or \$4.00 in 1982\$) could yield total production through 2020 of approximately 4800 EJ (assuming linear extrapolation between 1976, 1985, 2000 and 2020 plant estimates).

Since the WEC projection ends in 2020 one might expect some low cost gas to continue to be produced beyond 2020 (production in 2020 is still 114.8 EJ/yr). Suppose another 1700 EJ are producible below 2.50/GJ, so that the total is 6500 EJ. WEC posits a remaining recoverable resource of

*EJ - Exajoules, converted to EJ assuming 1 tcf = 20.2 Mt and 1.03×10^3 Btus/cf and rounding to the nearest 1000.

around 10,000 EJ. They propose that an equivalent \$20/bbl (1974 dollars) is a high price for gas (\$3.60/GJ in 1975\$ or \$5.70 in 1982\$).

Suppose that the remaining 3500 EJ estimated to be available in the WEC study (10,000-6,500) was available between \$2.50 and \$3.60 (1975 dollars). Our best guess resource estimate is 11,000 EJ. Let us suppose the remaining 1,000 EJ is available between \$3.60 and \$10.00/GJ. Since gas recovery rates are already very high (80%) it is unlikely that technology can achieve a significant increase in recoverable resources through enhanced recovery from existing fields. (Gas in tight formations and other forms of gas are included in the unconventional gas category.) To get further cost resolution on gas resources let us suppose that associated gas (Heede, p. 30, estimates it to be 85 gigatons or 4,600 EJ) is available at very low cost because it will be produced largely as a by-product of oil production (\$0.10 to \$1.50/GJ).

Thus, the best guess quantities by resource grade would be:

	Price (1975\$/GJ)			
	<u>.10-1.50</u>	<u>1.50-2.50</u>	<u>2.50-3.60</u>	<u>3.60-10.00</u>
Quantity (EJ)	4600	1900	3500	1000

To develop the distributions by cost grade from this information we use the same approach as for oil but we expand the highest cost grade to account for unconventional gas.

Unconventional Gas Sources

In addition to conventional deposits of gas, a variety of sources of gas exist in other types of deposits. Recovery from these deposits is technologically speculative and almost certainly quite expensive even if

technologically feasible. Some researchers have speculated that huge (unlimited amounts from the perspective of energy use to 2050 or 2100) deposits of gas of abiogenic origin exist uniformly below the earth's crust. Other sources that are speculative but have been examined in somewhat more detail are included in the table below. As can be seen, there is little data available for most sources outside the U.S. Costs of these speculative resources are even more speculative. To account for this we suggest that some of the cutoff of technological "feasibility" may be around \$15.00(1975\$). This is roughly consistent with note "a" in the table suggesting technical consideration of up to 2 to 4 times current prices of \$3-\$5/mcf (1979\$). We allow none of this unconventional gas to be available for the 3 and 16 percentile values. We add an additional 3,000 to the 50 percentile, 4,000 to the 83 and 40,000 to the 97th percentile to account for the most extreme speculation (noting that the probability is low if it is available at any price and, even if it is available, it is unlikely to be used because of the high price).

Technically Recoverable Resources of Unconventional Gas^a

<u>Resource Type</u>	<u>Estimate by</u>	<u>Resource Amount (10¹² ft³)</u>	
		<u>U.S.</u>	<u>Global</u>
Geopressured Gas	Various Authors, reported in U.S. DOE (1980, p. V.18)	44-5000 ^b	N.A.
	Potential Gas Agency, reported in ION (1979, p. 78)	53-256	N.A.
	USGS Bulletin #790 onshore & offshore onshore only	150-1500 97	N.A.
Gas from Tight Gas Formations	Lewin Associates, reported in Kuuskraa & Meyer (1980, p. 17)	110-200	370-860
	Potential Gas Agency, reported in ION (1979, p. 78)	70-300	N.A.
	NPC (1980, Vol. I, p. 27)	608	N.A.
Gas from Coal Seams	Kuuskraa & Meyer (1980, p. 43)	40-60	170-260
	Potential Gas Agency, reported in ION (1979, p. 78)	200-250	N.A.
	AGA (1980, p. 39)	10-60	N.A.
	NPC (1980, Vol. II)	44.7 ^c	N.A.
Hydrates Zones	—	N.A.	N.A.
Gas from Shales ^d	Kuuskraa & Meyer (1980, p. 26)	10-50	10-350
	Potential Gas Agency, reported in ION (1979, p. 78)	2-900	N.A.
	AGA (1980, p. 33)	60-600	N.A.
	NPC (1980, Vol. III, p. 4-5)	25.3-49.9	N.A.
Total ^e		126-6758	594-7020

N.A. Not available or no estimates made.

^acould represent a great deal of gas as much as the total estimate.

Technically Recoverable Resources of Unconventional Gas^a (Continued)

^a"Technically Recoverable" is that part of the resource base, including discovered, undiscovered, produced, and unproduced amounts, that is producible under a specified set of costs and technologies. It has been operationalized by examining specific technologies. No explicit economic criteria were applied in most cases. However, the fact that the technologies have been seriously explored implies some belief that production would occur at some plausible price. The sense of the literature is that the upper range of plausible prices is at most 2 to 4 times present natural gas prices of \$3-\$5/mcf.

^bMost authors based estimates on aquifers in Texas and Louisiana only; these are viewed as by far the most promising. Kuuskraa & Meyer (1980, p. 55) notes that reinjection could increase recoverable amounts by five to six fold.

^cHighest estimated recovery at \$9/mcf (the highest price considered).

^dRefers only to production of naturally occurring gas in shales; potential for synthetic gas from shale is excluded.

^eSum of the lowest and highest estimates for each resource. For the global total, U.S. figures are used when no global estimates are available or when the upper range value of the U.S. estimate is higher than the reported upper range value for the entire world.

Source: Reilly et al., 1983, p. 170-71.

INPUT ASSUMPTION

Coal Supply

NUMBER OF MONTE CARLO VARIABLES

5

VARIABLES INVOLVED

RIGISL, RIL, STISL, VISL

DATA FORMAT FOR MONTE CARLO ANALYSIS

Among the variables which determine coal supply, four are considered for Monte Carlo analysis. These are the graded resource amount (RIGISL), the 25 year elasticity (RIL), environmental costs (VISL), and technological change (STISL). Coal RIGISL and RIL are handled identically to oil and gas RIGISLs and RILs (see the discussion in the Conventional Oil Supply data sheet). Because of lack of data a single world coal distribution is chosen and regional coal resources are deterministically linked to that value. No regional distinction is made for RIL or STISL in the Monte Carlo analysis. VISL is specified in 1975 dollars/GJ and accounts for environmental costs imposed in the future (after 1975). If no additional environmental costs are imposed between 1975 and 2100, ENV would be 0.0; if environmental restrictions are relaxed it would be negative. VISL is specified for two regions; OECD = US + OECD PAC + WEUR & CAN and OTHERS = all other regions. STISL is specified as an annual percentage rate and acts to reduce the base cost of production each year by the specified percentage. Thus, it normally acts in the opposite direction of environmental costs and

exhaustion of high grade resources--i.e., it can make previously uneconomic grades of coal economically exploitable.

INTEGRATION WITH MODEL SPECIFICATION

For RIGISL and RIL, see the conventional oil data sheet. TC is regional in the model, but regional rates are deterministically linked to the single world rate in the Monte Carlo analyses, implying perfect correlation between regional rates. VISL enters the model directly and is specified separately for the nine regions. Subregions are deterministically linked to the values chosen for the two aggregate regions. The 1975 VISL values are 0 by definition. The specified VISL values are assumed to hold in the year 2050, earlier year estimates are interpolated between and later year estimates extrapolated from the 1975 and 2050 values.

POTENTIAL CORRELATION WITH OTHER VARIABLES

RIGISL

Among RIGISL. Since a single resource for the world is chosen, perfect correlation is implied. Complete independence is probably a better assumption. However, it is not possible to get reasonable estimates of uncertainty by region, whereas estimates for the world can be constructed. Using world measures of uncertainties for regions would lead to an underestimate of world uncertainty in resources unless regional resource uncertainties are perfectly correlated. Using a single

distribution gives a correct estimate of global uncertainty but will not yield solutions where, e.g., the US has high coal reserves while the USSR has low reserves. The latter is the less serious problem (see the worksheet discussion).

With other variables. We see no obvious correlation with other variables.

RIL

Among other RIL (oil, gas, etc). Since the same phenomena are involved for different fuels one might expect high correlation. If necessary, it may be possible to collapse the five RILs into a single Monte Carlo variable with the five values deterministically linked.

Assessed impact: positive correlation - strong.

With other variables. We see no obvious correlation with other variables.

VISL

Among VISL. Global pressures to safeguard the environment may lead to some correlation but this would probably be a very small factor. As knowledge about pollution and its impacts increase in one region, this knowledge becomes available worldwide through normal information channels, thus leading to a positive correlation.

Assessed impact: positive correlation - weak to moderate.

With labor productivity. See discussion in labor productivity data sheet.

Assessed impact:

OECD: positive correlation - moderate to strong

Centrally Planned: positive correlation - weak

LDCs: positive correlation - weak

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EXPERTS

Louis DeMouy - US DOE

Richard Gordon - Pennsylvania State University

Kurt Nagle - National coal Association

Walter Hibbard - Virginia Polytechnic Institute

Gordon Wood - US Geological Service

Gregg Marland - IEA

Ralph Rotty - IEA

Richard Heede - University of Colorado

Joe G. Baker - ORAU

*A seminar was held on August 5, 1982 to address the issue of coal resources and costs. seminar participants included Chester L. Cooper, Institute for Energy Analysis (IEA); Louis DeMouy, U.S. DOE; James A. Edmonds, IEA; Richard Gordon, Pennsylvania State University; Kurt Nagle, National Coal Association; Walter Hibbard, Virginia Polytechnic Institute; Frederick Koomanoff, U.S. DOE; Gregg Marland, IEA; John M. Reilly, IEA; Alvin M. Weinberg, IEA; and Gordon Wood, U.S. Geological Service. The Seminar is documented in "Summary of Dinner Seminar on Global, Long-Term, Coal Resources and Costs, August 5, 1982", Institute for Energy Analysis unpublished manuscript.

DISTRIBUTIONSCoal Supply ParametersRemaining Recoverable Resource Amounts (RIGISL)
(in exajoules)

	Percentile				
	<u>3</u>	<u>16</u>	<u>50</u>	<u>84</u>	<u>97</u>
Grade (1975\$/GJ)					
.13-.40	6,500	16,000	31,000	40,000	54,000
.40-.80	8,000	20,000	38,000	50,000	67,000
.80-1.60	12,000	33,000	54,000	76,000	97,000
1.60-2.70	13,000	44,000	74,000	92,000	110,000
2.70-5.30	13,000	44,000	74,000	215,000	355,000

25 Year Elasticity (RIL)

	Percentile				
	<u>3</u>	<u>16</u>	<u>50</u>	<u>84</u>	<u>97</u>
Elasticity Value (Assumed the same as for oil)					
	0.0	0.3	1.0	1.5	2.0

Technological Change (STISL)
(annual percentage change)

	Percentile				
	<u>3</u>	<u>16</u>	<u>50</u>	<u>84</u>	<u>97</u>
Value					
	-0.005	0.000	.005	.01	.02

Environmental Costs Add-on (VISL)

	(1975\$/GJ)				
	<u>3</u>	<u>16</u>	<u>50</u>	<u>84</u>	<u>97</u>
OECD	0.0	.60	1.60	3.00	8.00
Other	0.0	.40	.80	2.00	8.00

DISAGGREGATION TO MODEL REGIONS

<u>Region</u>	<u>Fraction</u>
USA	.257
WEUR & CAN	.079
OECD PAC	.061
EUSSR	.437
ACENP	.131
MIDEAST	.000054
AFR	.020
LA	.004
SEASIA	.012
	<u>1.00</u>

Based on total (remaining) resources from Reilly, et al. 1983,
p. 195. These fractions are assumed to hold for all grades.

COAL WORKSHEET

Most of the references in this section are from R. Heede, "A World Geography of Recoverable Carbon Resources in the Context of Possible Climate Change," Masters thesis, Dept. of Geography, University of Colorado, 1983. The major original source for coal resource estimates is the World Energy Conference's periodic Survey of World Energy Resources (most recent is 1980).

TABLE 1. REGIONAL RESOURCES AND RESERVES

	GTce		
	<u>Recoverable*</u> <u>Reserves</u>	<u>In-Place*</u> <u>Reserves</u>	<u>Remaining Resources*</u> <u>(Including In-Place</u> <u>Reserves)</u>
U.S.	191	344	2,873
Other OECD	127	208	1,569
Centrally Planned	324	426	6,345
LDC	<u>51</u>	<u>103</u>	<u>395</u>
	693	1,081	11,182

*WEC estimates from Reilly, et al., p. 195 using WEC conversion factors for coal equivalent (ce). (The resource estimate compares roughly with Heede's ce conversion of WEC estimates of 10,880--p. 59. The proved recoverable total is 688 GTce compared to our 693.)

Reilly et al., notes the low bias in WEC estimates for our purposes and mentions a possible global total of 33,000 GTce. Heede cites various researchers who believe more coal is available including Bazhenov, 9,000 GT (not ce) for China alone. Ikornihov estimates approximately 2,000 GT for China compared to the WEC estimate of 1,530 GT. For global reserves Matveyev suggests 20,000, 30,000 or even 40,000 GT as exploration continues (see Table 2).

TABLE 2. GLOBAL ESTIMATES OF COAL RESOURCES

<u>Author</u>	<u>Remaining Resources (Including In-Place Reserves)</u>
WEC (1978)	
UN (1980)	10,804
Nesterov and Salmonov (1977)	22,000
Fettweis (1976)	10,755
Matveyev (1976)	20,000 - 30,000 - 40,000
Averitt	15,000

Part of this difference may be due to definition. In defining resources WEC (1980) states (p. 48) "The estimates provided for additional resources reflect, if not certainty about the entire quantities reported, at least a reasonable level of confidence. Resources whose existence is **entirely speculative are excluded.** " (Emphasis added.)

It is difficult to know what they mean here. The emphasized sections seem in conflict. the first statement suggests the stated level of confidence should apply to the total or totals (whether this is the world total, total for countries, total for hard coal versus brown coal versus lignite, etc., is still unclear). However, the second statement, in arguing that

entirely speculative resources are excluded, implies that individual resource deposits or fields are (at least informally) ranked and those which fall below the "entirely speculative" cutoff are totally excluded. This suggests that the confidence applies to deposits, fields, or basins, rather than totals. While perhaps seemingly an academic argument, if they mean anything other than that the confidence applies to the world total, the rules of statistics suggest extremely high confidence in the world total supposing there is some degree of independence among the sub-totals. Suppose there were 10 subcategories of equal size, with the total resource being 10,000 GT, and subcategories estimates were normally and independently distributed. Further, assume that "reasonable level of confidence is taken to mean the one standard deviation level, implying that the chance that the coal resource for each subcategory was greater than the reported amount is 84 percent or alternatively there is only a 16.0 percent chance it would be less. If the 10 subcategory estimates are independent and normally distributed with a mean of 1200 then the probability that the world resource was less than 10,000 GT would be less than .1 percent. That is, one would be at least 99.9 percent confident that resources were at least 10,000 GT. Even if there are only three subcategories the probability is 95.8 that resources are at least 10,000 GT.

Supposing that the expressed confidence is in country totals then there are three main subcategories (US, USSR, and China) of roughly equal resource magnitudes. If independence of estimates between countries exists (and it seems justified), and if the 16.5 percent confidence assumption is reasonable (it seems to be a justifiable if not a high value interpretation of the phrase "reasonable confidence"), then it is virtually certain that world resources are at least as much as the WEC estimate.

Another problem in comparing estimates is that some are estimates of geologic resources, implying something akin to the total amount in the earth's crust, where others include the total of all resources in-place but only in deposits where at least some of the resource is economic; still another set of estimates attempts to count only recoverable amounts thus excluding both portions of in-place resources which are uneconomic and entire deposits which are uneconomic.

We, of course, eventually need estimates of the last category, by resource grade. Heede makes such estimates based on the WEC resource estimates. But he supposes that 40 percent of the WEC resources are in uneconomic deposits and applies a recovery factor, which averages just under 60 percent, to the remaining 60 percent of the WEC estimate. Thus, recoverable amounts are only 36 percent of the WEC estimated resource. Heede cites Fettweis' argument concerning the "geotechnical" difficulties of recovering coal from many of the deposits included in the WEC estimates. WEC claims all their additional resources would "become of economic value" (emphasis added). Resources can "become" of economic value for a variety of reasons including further exploration, higher coal prices, improved technology. WEC doesn't specify how those resources might "become" economic. This discussion makes obvious the need to introduce economics.

Economics

Heede notes a host of socio-eco-technical reasons for inclusion or exclusion of coal deposits as reserves, including such things as availability of transportation facilities, distance to market, the availability

of geologists, environmental concerns, along with seam thickness, etc. The IEA/ORAU model separates the socioeconomic from the purely technical factors and provides separately for technological improvement and environmental factors. The socioeconomic factors are accounted via the supply elasticity; given time many of these problems can be resolved at little or no additional cost per unit. For instance, engineers and geologists can be trained, transport facilities built, or coal using industry or even populations may relocate to areas near the coal fields as the aluminum industry moved to the TVA and BPA areas in the U.S. for cheap electric power and as the chemical industry is currently starting up in the Middle East to take advantage of cheap natural gas. Technological improvement and the environment are, of course, explicitly modeled.

Thus, the resource amount should express grades of resources if deposits had to be exploited with existing mining technologies, but recognizing that the socio-economic milieu in which the resources are located can change. At the same time we should erase the conservative bias in the distribution due to exclusion of "speculative" resources.

The WEC has also attempted to give some idea of the economics of resources. They propose four grades which are (in 1979 \$'s per ton): less than 15, 15 to 30, 30 to 60, and greater than 60. However, there are some problems with this categorization for our purposes since it applies to reserves. By definition, reserves are economic deposits and since in most countries coal prices were less than \$60/ton, coal which might cost more than \$60 is excluded. European coal is the primary exception since protection of the domestic coal industry keeps prices higher. (Lignite resource grading suffers a similar truncation problem since lignite is a poorer

grade of coal and therefore it must be priced below bituminous coal.) In addition, not all countries responded. However, there was a fairly comprehensive reporting of OECD countries and a good number of developing countries with relatively large amounts of coal also reported.

The table below represents an aggregation of the WEC estimates.

TABLE 3. RESERVES BY REGION AND COST CATEGORY

	1979 \$ per tce* (gigatons)				
	<u>5-15</u>	<u>15-30</u>	<u>30-60</u>	<u>>60</u>	<u>Total</u>
U.S.	66	90	34	NR	190
Other OECD	14	20	44	35	113
LDCs	29	11	<1	<1	41
Centrally Planned**	<u>NR (113)</u>	<u>NR (153)</u>	<u>NR (58)</u>	<u>NR</u>	<u>324</u>
Total	222	274	136	35	668

NR = None reported

*The following adjustments were made. For sub-bituminous coal WEC assumes a .78 conversion coefficient to coal equivalent. Thus, sub-bituminous coal in the 5-15/ton category was evaluated as falling in the \$6.40-19.23/tce category. It was assumed to be uniformly distributed across this grade implying that only 66 percent of sub-bituminous listed in the 5-15/ton category should be included in the 5-15/tce category--the remaining 33 percent belongs in the 15-30/tce category. WEC gives lignite conversion coefficients varying from .3 to .6. The process listed above is used to make lignite grades and amounts comparable, and similarly for peat.

**Figures in parentheses are derived assuming the same proportion of the recoverable reserves fall in each grade as in the U.S.

NOTES: 1. The above figures are based on the best available information as of 1979. 2. The above figures are based on the best available information as of 1979. 3. The above figures are based on the best available information as of 1979.

TRANSFORMED TO THE 1979 \$ PER TCE.

It shows some of the problems discussed earlier--most notably the U.S. lists no reserves in the >\$60/ton category. A similar problem exists for Canada and Australia but it is hidden by the aggregation with Western Europe. Like problems may exist in the developing countries.

We can contrast this with regional estimates of recoverable resources. Table A-4 is from Heede (Table C-2).

TABLE 4. ESTIMATES OF REMAINING RECOVERABLE RESOURCES BY REGION

	<u>Parent (1979)</u>	<u>Fettweis (1976)</u>
U.S.	940-1168	405
Other OECD	454	120*
LDCs**	674	82*
Centrally Planned	<u>3,416</u>	<u>469</u>
Total	5,712	1,076

*For countries not estimated separately recoverable resources set equal to proved reserves.

**Heede only breaks out 11 major countries and the rest of the world. All countries listed as rest of world are assumed to be LDCs. This probably overstates estimates for LDCs.

Estimates of recoverable resources for the world as a whole are given in Table A-5.

TABLE 5. GLOBAL ESTIMATES OF RECOVERABLE RESOURCES

(gigatons)

<u>Author</u>	<u>Recoverable Remaining Resources</u>	<u>Total Resources</u>
Parent	5,712	11,421
Fettweis	1,076	10,755
Nesterov and Salmonov	13,500-15,500	22,000
BGR	1,847 ce	NG
Hubbert	2,000-7,000	NG
Heede	4,190 ce	13,476*

ce = coal equivalent

*Uses WEC estimate

As noted, however, there are different assumptions about becoming economic, etc. Nesterov and Salmonov with the highest total claim that their lower estimate, 13,500 GT, is recoverable under conditions in 1975. The higher total is available by 2000 under their assumptions of how conditions will change.

As can be seen, the few regional estimates (Table A-4) in no way represent the uncertainty portrayed in the global estimates--even if regional high and low estimates are perfectly correlated one does not get the distributions for global estimates given in Table A-5.

Thus, we have decided to go only with a single global distribution of resources and deterministically link regional resources. The bias this will yield is that situations where one region has relatively high resources while another has relatively low resources are eliminated.

The Resource Distribution

We developed the resource distribution as follows. First, unless noted all estimates given above were tons of coal rather than coal equivalent. We convert to ce assuming the average global conversion for WEC which is .83. We take Fettweis' total resources as indicative of nearly assured recovery under present conditions (today's technology and roughly \$60/ton) since it is basically proved recoverable reserves.

For the 3 percent probability category, we assume resources are distributed by grade as given by WEC; all amounts not explicitly listed by WEC are assumed to be of the most expensive grade in Fettweis' total (i.e., \$30-\$60). We assume that at higher costs (\$60-\$200/ton) Fettweis' resources estimate can be doubled and that this additional 892 GTce are evenly divided between the 60-100 and 100-200 dollar categories. Altogether, the total recoverable resource in the 3 percent probability category represents only 16 percent of the WEC estimate of remaining resources in place.

For the 50 percentile values we interpret Heede's estimates similarly to Fettweis'. For the higher grades we assume that total resources are 16,000 GT compared to WEC's approximately 13,500 GT. These are converted to ce, Heede's 6000 GTce resource base is subtracted and it is assumed that, identical to Heede's assumption for the 6000 GTce, 69.8 percent of the in place resource is recoverable and that this is evenly divided between the \$60-100 and \$100-200 category.

For the 97 percentile bracket we take Nesterov and Salmonov 13,000 GT value which they claim producible under 1975 conditions. Here we assume

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February 1981

this is divided among the \$5-100/ton categories. Grade proportions are assumed to be the same as for the 3 and 50 percentile values. For the highest category (\$100-200) we assume that the total resources is Matveyev's high value--40,000 GT--converted to ce, and exploited at the average recovery factor implied by Nesterov and Salmonov (.705) minus the amounts Nesterov and Salmonov assume recoverable in lower cost grades.

These are converted to EJ at 29.29×10^9 joules/mtce and 1975\$ = .781 X1979\$.

TABLE 6. RECOVERABLE RESOURCES OF COAL BY GRADE AND UNCERTAINTY
(10^9 tons ce)

Grade (1979\$/mtce)	Percentile				
	<u>3</u>	<u>16</u>	<u>50</u>	<u>84</u>	<u>97</u>
5-15	222	550	1,043	1,369	1,859
15-30	274	679	1,287	1,690	2,295
30-60	396	1,128	1,860	2,588	3,316
60-100	446	1,492	2,538	3,136	3,735
100-200	446	1,492	2,538	7,336	12,186

Technological Change

We would like a measure of total productivity--output divided by all inputs. Cost per unit output is such a measure but is often clouded by other factors. The post-1970 experiences are muddled by many factors (see

Baker) which are related to the environment--safety issue, rapid expansion due to demand pressure (elasticities), etc. The pre-1970 experience, according to U.S. DOE data, shows real prices of U.S. bituminous coal at mine mouth declining by an average of 2.3 percent per year. For anthracite the decline was 2.1 percent per year, thus indicating possible improvement in technology or organization. This is quite rapid by most standards. However, not all of the change may be attributable to technological change. The industry was in decline during this period, many small mines were closing, thus the easiest, cheapest mines were left operating. While some of this reduction may be thought of as weeding out inefficiency, and therefore an improvement in technology in a broad sense, the 1970s brought many of these mines back, still inefficient. Thus, a good portion of this change may represent the elasticity of supply effect. Declining demand during the 1950s and 1960s may have led many mines to sell coal at prices that did not cover the full cost of opening and operating mines given the expectation of declining costs.

The typical interpretation of technological change (particularly if one separates environmental costs) would have it bounded at 0.0 percent (once the technique is discovered it is not undiscovered). In the aggregated accounting used here this bounding need not hold even if one excludes dislearning. In particular, real increases, in labor costs for example, would generate real cost increases if no compensating technological improvement occurred.

We suppose that the 50 percentile value is a .5 percent per year improvement. We set the 3 and 97 percentile values at -.5 and 2.0 percent

A.B. for the 50 percentile value we suggest 50/percent.

per year. Allowing for possible negative improvement due to rising real capital or labor costs. The 16 and 84 percentile values are set at 0.0 and 1.5.

Environmental Costs

Included among these costs are various environmental and safety related costs associated with mining as well as environmental costs associated with use, but exclusive of technological change in pollution control. The table below contains largely subjective estimates of possible future pollution costs for coal mining and use. They are broadly based on the observation that pollution control, health, and safety costs for the U.S. were estimated to total about \$12 to \$20 (1977\$) per ton in the 1970s depending on the type of mine (see Reilly, et al. (1983), pp. 209-23.

Environmental Add-On Costs

	Percentile (1977\$/ton)				
	<u>3</u>	<u>16</u>	<u>50</u>	<u>83</u>	<u>97</u>
OECD	0.0	15.00	35.00	75.0	200
Other	0.0	10.00	18.00	50.0	200

INPUT ASSUMPTION

Shale Oil Supply

NUMBER OF MONTE CARLO VARIABLES

5

VARIABLES INVOLVED

RIGISL, RIL, STISL, VISL, cost scale factor.

DATA FORMAT FOR MONTE CARLO ANALYSIS

The variables interest and the format for the variables are similar to the coal parameters (see the coal data sheet) and are handled identically.

INTEGRATION WITH MODEL SPECIFICATION

In the model the oil shale supply characterization is handled similarly to coal supply (see the coal data sheet). However, the breakthrough technological cost is also randomly determined via a scale factor applied to the cost distribution. This procedure explicitly deals with the problem that resource amounts of particular grade are not independent of estimates in other grades. (See the discussion relating to coal and the attached oil shale worksheet.)

Many researchers think in terms of implicit or explicit models, for which resource grades (or the breakthrough costs) of shale oil are not specified explicitly but rather are implied in total resource estimates. Thus, some might conclude that as a low estimate shale oil resources are zero, because they may never be exploited. What such a statement may

really imply is that there is some positive amount of the resource but it is of such poor quality (it will cost so much to exploit) that it will never be used. The model is designed so that it is entirely possible to have a massive resource potentially available but none is ever actually used. This point is developed further in the attached shale oil worksheet.

POTENTIAL CORRELATION WITH OTHER VARIABLES

The same potential correlations exist as for coal. (See the coal data sheet discussion.)

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R. Heede

Michel Grenon

DISTRIBUTIONS (see worksheet)Global Oil Shale Resource Grades (EJ)*

Cost Grades (1975\$/GJ)	Percentile				
	<u>3</u>	<u>16</u>	<u>50</u>	<u>83</u>	<u>97</u>
1.90-3.80	1,200(0)	14,400(300)	26,600	38,900	52,000
3.80-6.40	5,300(0)	26,600(1000)	52,000	245,000	550,000
6.40-12.80	42,000(0)	120,000(1000)	500,000	920,000	1,500,000
12.80-25.50	52,000(100)	490,000(10,000)	1,500,000	1,800,000	2,700,000

Cost Grade Scale Factor*

	Percentile				
	<u>3</u>	<u>16</u>	<u>50</u>	<u>83</u>	<u>97</u>
Value	1.0	1.70	2.0	4.0	6.0

25 Year Elasticity**

	Percentile				
	<u>3</u>	<u>16</u>	<u>50</u>	<u>83</u>	<u>97</u>
Value	0.0	0.3	1.0	1.5	2.0

Technological Change**
 (Annual percentage change)

	Percentile				
	<u>3</u>	<u>16</u>	<u>50</u>	<u>83</u>	<u>97</u>
Value	-0.005	0.000	0.005	0.01	0.025

Environmental Add-on Costs
 1975\$/GJ

	Percentile				
	<u>3</u>	<u>16</u>	<u>50</u>	<u>83</u>	<u>97</u>
	0.0	.40	1.30	6.40	12.80

*The cost grade scale factor is not implemented in the current analysis. Resource amounts were altered (figures in parentheses) to reflect uncertainties represented in the cost grade scale factor.

**Assumed to be the same as for coal.

DISAGGREGATION TO MODEL REGIONS

Resources

<u>Region</u>	<u>Fraction</u>
USA	.176
WEUR & CAN	.081
OECD PAC	.059
EUSSR	.161
ACENP	.081
MIDEST	.020
AFR	.241
LA	.121
SEASIA	.061

Based on shale oil resources with a yield of 25-100 gallons per ton of shale. From Reilly, et al., 1983, p. 67. USA based on North America. LA based on South America. WEUR & CAN based on Europe. OECD PAC based on Australia and New Zealand. EUSSR assumed 1/2, ACENP 1/4, SEASIA 3/12 and MIDEAST = 1/12 of Asia.

ENV

The environmental add-on in non-OECD regions is assumed to be .70 of the Monte Carlo value. In the OECD regions (US, WEUR & CAN, OECD PAC) it is the selected value.

WORKSHEET -- OIL SHALE

Oil shale resources are very poorly known and there are few countries that have evaluated known deposits or conducted broad geological surveys to establish the existence of deposits. There are even fewer countries that regularly update estimates. Thus, while there are recent literature citations for many countries, the actual estimates may date back 40 years. However, in most cases where revisions based in new geological surveys have been made, the revisions have been upward.

(The preceding discussions paraphrases Grenon.)

While it would be useful to have better estimates of resource amounts, the critical future use of CO₂ is how much of what appears to be an enormous resource, will be used. The focus is therefore on costs.

Resource Amounts

The following table gives an indication of amounts of potentially recoverable oil shale, by region, by degree of certainty, and by one grade dimension (yield per ton). Many other factors are important in determining resource grade such as deposit depth, size, and location. The relative economics of production from particular deposits can also change depending on the type of technology: advances in in-situ technologies could make deeper deposits less costly relative to surface deposits; improvement in hydrogenation techniques could greatly increase the yield from the extensive Eastern U.S. shales; etc.

Cost Estimates

The following table gives some recent shale oil cost estimates.

COMPARATIVE COSTS OF SHALE OIL

(1979 dollars per barrel of oil equivalent)

<u>Source/Date</u>	<u>Cost</u>
Cameron Engineers/1979 ^a	14.5 - 25
Pace/1979 ^b	26
ICF Incorporated/1979 ^c	32
Mellon Institute/1980 ^d	17 - 25
OTA/1980 ^e	48 - 62
Bechtel	39

^aFrom Cameron Engineers, 1979, "Overview of Synthetic Fuels Potential to 1990" in Synthetic Fuels, United States Senate, Committee on the Budget, Subcommittee on Synthetic Fuels (Washington, D.C.: U.S. Government Printing Office, September 27, 1979), p. 177. Prices per barrel are converted from prices per barrel at 6×10^6 Btu per barrel to the equivalent price per barrel at 5.8×10^6 Btu per barrel. Cost ranges encompass different estimates of investment costs per barrel for a single technique, but also differential costs for different techniques. Reported as the selling price.

^bSenate testimony of S. Frank Culbertson, President, Rocky Mountain Division, Pace Co., Consultants and Engineers, Inc., in U.S. Congress, Senate, Committee on the Budget, Costs and Economic Consequences of Synthetic Fuels Proposals, 96th Cong., 1st sess. (Washington, D.C.: Government Printing Office), p. 13.

^cReport in ICF Incorporated, 1979, "Oil Import Reduction: An Analysis of Production and Conservation Alternatives," in Synthetic Fuels, United States Senate, Committee on the Budget, Subcommittee on Synthetic Fuels (Washington, D.C.: U.S. Government Printing Office), p. 278. Reported as expected costs under the administration's proposals for synfuels.

^dFrom Richard H. Shackson and H. James Leach, Using Fuel Economy and Synthetic Fuels to Compete with OPEC Oil (Arlington, Virginia: Mellon Institute, Energy Productivity Center, 1980). Shale costs are based on Bechtel estimates. Costs are for secondary liquids (transportation fuels). The coal liquids technology is direct conversion to methanol. Biomass technology is ethanol from corn.

^e48-62, range depending on rate of return and technique used. From Congress of the United States, Office of Technology Assessment, An Assessment of Oil Shale Technologies, Report No. OTA-M-18 (Washington, D.C.: U.S. Government Printing Office, 1980), p. 16. Converted to 1979 dollars.

^fFrom H. F. Brush, Bechtel Corp., "Readiness: Where Do We Really Stand?," paper presented at the Government Research Corporation Conference, "Synthetic Fuels: Worldwide Outlook for the 80s," San Francisco, California, 19-20 February, 1981, p. 24.

As can be seen a considerable range exists. On the low side, Cameron Engineers argues that their costs are for production costs only, not including various costs of getting the oil to market. On the high side, OTA makes a rough upward adjustment for "marketing" factors, beyond their estimated production costs.

Development of the Resource Distribution

To independently recognize the uncertainty in resource size by grade and cost without actually having to specify how much the uncertainty is due to uncertainty about existence of deposits versus into what grade category they fall, we use the following approach.

First, we develop resource uncertainty bands for resource categories. We then develop an uncertainty band for a scale factor applied to cost units for the grades. The base resource grade categorization is developed on the most optimistic assumptions about the technology. Therefore, the scale factor is bounded from below by 1.0. The resource amounts in each category are developed as if no uncertainty exist about what category resources fall in but only about the existence of the deposits. This appears to be the best compromise available between what can credibly be done given existing information and an ideal representation.

The following assumptions are made. The lowest cost grade is \$15/barrel (Cameron Engineers estimate). This is somewhat more optimistic than Cameron Engineers since our \$15 refers to a price at which crude equivalent could be sold rather than a production cost. We assume that (whatever the base price) the minimum amount of resource available (3 percentile limit) is what is called "recoverable under present conditions."

For the maximum (97 percentile) we assume one-half of the total (known, extensive, unappraised) in the 25-100 yield category. Only one-half is included on the basis that the other one-half would be more costly due to other grading considerations. For lack of any evidence to the contrary we assume the 50 percentile value is mid-way between the extremes. The 16 and 83 percentile limits are ± 2000 from the 50 percentile value.

For the next grade we take one-half known and possible extensions for the 25-100 yield shale for the 3 percentile limit. For the 97 percentile limit we take the remaining one-half of the 25-100 yield grade plus one-fourth of the 10-25 grade. For the 50 percentile values we take only the remaining one-half of the 25-100 yield resource.

For the next grade, we take the remaining one-half of the 25-100 yield and one-half of 10-25 yield resource for known and possible extensions for the 5 percentile limit. For the 97 percentile value we take the remaining three-fourths of the 10-25 yield resource. For the 50 percentile value we take one-fourth of the 10-25 yield resource.

For the next grade we take the remaining one-half of the 10-25 yield plus one-fourth of the 5-10 yield known and possible extensions for the 5 percentile limit. For the 97 percentile limit we take one-fourth of the 5-10 yield resource. For the 50 percentile value we take the remaining three-fourths of the 10-25 yield resource.

For the cost grade scale factors the 3 percentile value is 1.0 by design. Our best guess for the breakthrough price of shale oil is in the \$30 to \$60/barrel range, so the 50 percentile value is 2. \$25/barrel is our estimate for the 16 percentile limit, so the scale factor is 1.67. For the 97 percentile limit we choose 90 dollars, or a scale factor value of 6.0. For the 83 percentile value we choose \$60/barrel.

Global Oil Shale Resource Grades
(billions of barrels of oil equivalent)

Cost Grades (1979\$/barrel)	Percentile				
	3	16.5	50	83.5	97
15-30	200	2,350	4,350	6,350	8,500
30-50	860	4,350	8,500	40,000	89,750
50-100	6,860	20,000	81,000	150,000	240,000
100-200	8,550	80,000	240,000	300,000	440,000

These are converted to EJ at 6.119×10^9 joules/barrel of oil equivalent. 1979\$ per barrel are converted to 1975\$/GJ at $1975\$ = .781 \times 1979\$$.

25 Year Elasticity and Technological Change

For the 25 year elasticity and technological change parameters we assume the same values as for coal. Given that little data are available for shale oil, coal mining seems to be a reasonable, analogous industry.

Pollution Costs

Current estimates of pollution costs do not seem to be particularly relevant to the potential pollution problems of large scale development. Total estimated pollution costs for air and water pollution control, land reclamation, and water diversion represent roughly \$1.16 to \$3.23 (1979\$) per barrel of oil produced. (See Reilly, et al., 1983), p. 89. If we convert these to per short ton of coal equivalent, the range is from \$4.40 to \$12.20 (1979\$), or given that the expected yield per ton of shale is around 25 barrels per ton of shale to pollution cost per ton of shale is \$25 to \$70 per ton of shale. Thus, per ton of energy bearing material used, the pollution costs of shale oil mining and retorting tends to be higher than coal mining, but per unit of energy it is cheaper. But, again, control of significant potential pollution problems (ground water pollution

from nonpoint sources) are not included in the pollution cost calculations. Thus, we believe the currently estimated pollution costs are somewhat on the low side of what pollution costs may be when significant production occurs, and considerably more uncertainty exists than for coal.

Thus, we take the \$3.23/barrel to be the 16 percentile value, \$10/barrel as the 50 percentile value, \$50/barrel as the 83 percentile and \$100/barrel as the 97 percentile value all in 1979\$, then are converted to 1975 \$s at $1975\$ = .781 \times 1979\$$ and 6.119 GJ per barrel oil equivalent.

INPUT ASSUMPTION

Nuclear Power Supply

NUMBER OF MONTE CARLO VARIABLES

4

VARIABLES INVOLVED

RIGISL, VISL, Cost scale factor, STISL

DATA FORMAT FOR MONTE CARLO ANALYSIS

The following variables require input distributions for nuclear power supply: technological change, environmental costs, the graded resource, and, as in the case of shale oil, a cost scale factor. While the cost of nuclear power is graded because of uranium supplies, the cost is specified as the busbar cost of electricity generated from nuclear power rather than uranium costs. Thus, the parameterization of the distribution includes uncertainty in the technology of converting uranium to electric power as well as in the supply of uranium. Energy amounts are also estimated as amounts of electricity producible from the fuel rather than heat generated by the reaction.

This parameterization allows the consideration of near breeder or breeder reactors as a potentially lower grade (higher cost) source of nuclear electricity available in, for practical purposes, unlimited quantities. Technological change is specified as an annual rate of change. Environmental costs are specified as an add-on, in dollars per unit of electricity produced, and are handled identically to the environmental costs for coal. (See the Coal Data Sheet.)

INTEGRATION WITH MODEL SPECIFICATION

Nuclear power costs are specified by region in the model. A single distribution of resource grades implicitly assumes that uranium is traded among regions as necessary. We further assume that the single value chosen for each variable holds in all regions.

POTENTIAL CORRELATION WITH OTHER VARIABLES

Similar to other supply parameters. (See the Coal Data Sheet.)

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DISTRIBUTIONS

	Resource Amounts*				
	(in exajoules)				
	Percentile				
Grade (1975\$/GJ)*	3	16	50	84	97
3.41-7.60	800(0)	1,000(10)	1,500	1,800	2,900
7.60-10.90	1,900(0)	4,000(100)	8,000	10,000	14,000
10.90-11.00	1,000,000(0)	-- (1000)	--	--	2,000,000
			(1,500,000)	(1,750,000)	

*busbar cost
**breeder

	Cost Scale Factor*				
	3	16	50	84	97
Value	1.00	1.50	2.00	3.00	5.00

Environmental Add On
(1975\$/GJ)

	Percentile		
	3	50	97
Cost	0.00	10.00	100.0

	Technological Change		
	3	50	97
% per year	0.0	.005	.015

*The cost scale factor has not been implemented in the current version of the analysis. Resource amounts were changed (the figures in parentheses) to somewhat reflect the uncertainty represented by the cost scale factor. In addition, the median cost scale factor was applied to all grades.

DISAGGREGATION TO MODEL REGIONS

<u>Region</u>	<u>Fraction</u>
USA	.073
WEUR & CAN*	.134
OECD PAC*	.065
EUSSR	.178
ACENP	.085
MIDEAST*	.001
AFR*	.294
LA	.155
SEASIA*	.014
	<u>1.00</u>

*Perry aggregates these regions. Shares for these regions are based on WEC <\$80 U₃O₈ from worksheet.

Based on Perry's resource estimates from worksheet.

NUCLEAR POWER WORKSHEET

The following table provides estimates of uranium resources. The WEC estimates are very similar to the IAEA resource estimates which are widely recognized as being too low because they are based on exploratory data when exploration has not progressed very far. Perry attempts to provide a better estimate of world resources by using the U.S. (which has been relatively well-explored) to extrapolate to other regions. However, he suggests his estimates are also conservative because they exclude possible and speculative resource categories. Milton Searle, in an early effort, suggested that 5 percent confident limits on U.S. uranium resources alone were 7.7 million tons on the low side and 29 million tons on the high side, but the methodology used has been criticized.

An additional consideration is the conversion technology. The CANDU reactor system with fuel recycle produces almost three and one half times as much electricity per ton of U_3O_8 as the LWR without recycle (see next table). Other technological options fall in between these extremes. But options like the LMFBR use negligible amounts of uranium and therefore offer a nearly unlimited supply of power. Near breeders represent an additional technological possibility. Thus, the technology offers an additional degree of uncertainty as to how much energy is available from uranium resources. Obviously, a large determinant in the choice of technology is cost and as uranium costs rise technologies which make better use of uranium become more attractive. However, since uranium costs are a relatively small proportion of the total cost, relatively small variation

Uranium Resources(10³ metric tons uranium; 1979 dollars)

<u>Region</u>	<u>WEC^a</u>		<u>Cumulative Prod. to Jan. 1, 1979</u>	<u>Perry Extension from U.S. Occurrences^b</u>	<u>+40%^c</u>
	<u>\$80/kg</u>	<u>\$80-130/kg</u>			
U.S.	1310	558	260	1696	2375
CAN&WEUR	695	773	152	4604	6500
JANZ	337	15	9		
EUSSR	1855	18	417	4140	5880
ACENP	166	NR	50	1980	2800
MIDEST	4	NR	0		
AFR	810	311	147	7200	10000
SEASIA	39	8	0		
LA	258	11	0.6	3600	5000
Total	5474	1695	1036	23,220	32,500

NR = None Reported.

^aWorld Energy Conference Survey of Energy Resources 1980, WEC, London 1980.^bA. M. Perry, World Uranium Resources, International Institute for Applied Systems Analysis. Vienna, 1978.^cUsing Perry extrapolation technique, but including U.S. possible and speculative resources in extrapolation base.

Uranium Requirements of Power Reactors

<u>Uranium Requirements Per 21 GWyr^a</u>	<u>Tons U₃O₈</u>
LWR, no recycle	6010
LWR, recycle	4750
HTGR, no recycle	4310
HTGR, recyle	1770
CANDU, no recycle	4380
CANDU, recycle	1770
LMFBR, recycle	negl.

^a21 GWyr(e) is the electricity produced by one GW(e) reactor running at a 70 percent capacity factor for 30 years.

Sources: Wolf Hafele, Project Leader, Energy in a Finite World: A Global Systems Analysis, Report by the Energy Systems Program Group of the International Institute for Applied Systems Analysis (Cambridge, Massachusetts: Ballinger Publishing Co., 1981) and Hans Bethe, "Relative Merits of Alternative Fuel Cycles," in Nuclear Energy and Alternatives (Cambridge, Massachusetts: Ballinger Publishing Co., Cambridge, Massachusetts, 1977).

in the non-uranium costs can change the "break-even" uranium cost (i.e., the necessary cost of uranium so that the cost of electricity from lower capital but higher fuel cost LWRs equals the cost of electricity from breeder reactors. Chow estimates the break-even price to be \$150 to \$220/lb U_3O_8 (1978\$). But by varying the various factors that determine costs, the break-even price could be as low as \$28/lb or as high as \$330/lb as can be seen from the following table. (The high estimate is based on the difference between the high cost LWR and high cost LMFBR--the largest difference is between low cost LWR and high cost LMFBR, implying a break-even price of almost \$700/lb U_3O_8 , but this is probably quite unlikely since many of the factors that generate high nonfuel costs for LMFBR also lead to high nonfuel costs for LWR.)

Economics of Resources

Perry does not explicitly state the cost at which the estimated resources would be available. Since he extrapolates from U.S. reserves which are available at less than \$130/kg (1979\$), one might extrapolate the same grade range to other regions of the world as well. However, one might make the argument that the more easily available resources tend to be found first, thus there might be some tendency for resources not yet found to be more expensive. One can also note that the graded resources of the WEC show a much larger share of resources in the less than \$80/kg. There does not appear to be a good geologic explanation for such a distribution and one might therefore tend to believe the reasons are economic; with plenty of cheap ore available at present, the more expensive deposits have been ignored. Thus, we believe that a large proportion of the resources

Nuclear Electricity Generation Cost Summary

(1979 dollars)

	LWR			LMFBR		
	Low	Best Estimate	High	Low	Best Estimate	High
Capital Cost (dollars/kw installed capacity)	950	1100	1800	135	1600	3050
Capacity Utilization (percent)	70	65	60	70	65	60
Real Fixed Charge Rate (percent)	8	10.3	12	8	10.3	12
Capital Cost (mils/kwh)	12.4	19.9	41.1	14.8	28.9	69.6
Fuel Cycle Cost ^a (mils/kwh), Once-Through Cycle	7.1	7.6	9.0	NA	NA	NA
Fuel Cycle Cost (mils/kwh) Recycle	7.9	9.0	9.4	3.2	4.0	4.4
O&M (mils/kwh)	1.8	5.0	6.8	3.3	9.2	12.5
Decommissioning	<u>.1</u>	<u>.2</u>	<u>.4</u>	<u>.1^c</u>	<u>.3^c</u>	<u>.7</u>
Total Costs (mils/kwh) Once-Through	21.4	32.7	57.3	NA	NA	NA
Recycle	22.2	34.1	57.7	21.4	42.2	87.2

^aUranium at \$35/lb. = 3.54 mils/kwh.

^bNo estimates were given at these levels but all studies giving estimates for LMFBR O&M costs indicated them to be at least as high as LWR O&M costs. The best and high estimates are proportional to LWR costs.

^cAssumed to be 1 percent of capital change--identical to LWR cost.

Source: Reilly et al., 1983.

Research Institute for Energy Economics and the Environment, 1983.

included in Perry's estimate should go to the higher cost grade and probably some to grades more costly than \$130/kg. However, the extension of Perry's estimate (32.5 million tons) appears to be a better starting point as a 50 percentile guess. In addition, we need to consider more expensive grades than \$130/kg (approximately \$50 lb. of U_3O_8) given that the breeder may not be competitive until U_3O_8 reaches \$100/lb. or more. Given the tremendous uncertainty we propose only two grades of uranium (<80kg and >80kg) with the third grade of nuclear resource being breeder technology. Thus, for uranium availability we propose the following:

Uranium Resources (10^3 metric tons)

	Percentile				
	<u>3</u>	<u>16</u>	<u>50</u>	<u>84</u>	<u>97</u>
<80kg	5,500	7,000	10,000	12,000	20,000
>80kg	5,500	11,000	22,500	30,000	40,000

To convert this to electrical energy we assume a technology mix of medium efficiency reactors (2500 tons U_3O_8 /21gw yr(e)). Since we also create a distribution of cost factors which scale up the cost, the cost grades are the most optimistic.

Resource Amount (exajoules of electricity production)

	Percentile				
Mil/kwh (1979\$)	<u>3</u>	<u>16</u>	<u>50</u>	<u>84</u>	<u>97</u>
22-25	800	1,000	1,500	1,800	2,900
35-50	1,900	4,000	8,000	10,000	14,000
50.*	100,000				200,000

*Breeder available--essentially no limit. To convert from mils per kwh to dollars/gj multiply by .2777. To convert to 1975\$ from 1979\$ multiply by .781.

INPUT ASSUMPTION

Solar, Wind, and Other Renewable Electric

NUMBER OF MONTE CARLO VARIABLES

2

VARIABLES INVOLVED

CSLT, STISL

DATA FORMAT FOR MONTE CARLO ANALYSIS

The data format is similar to nuclear power, however because of the broad group of technologies included, we do not account for resource availability separately. While we use "solar" as a major base for costing, we allow considerable uncertainty to account for unforeseen technologies and breakthroughs (e.g., fusion). Since most meaningful estimates of solar costs are based on future costs under assumptions of further technological advance and economies of mass production of components, the cost distribution aims for costs in the year 2000.

A single distribution is needed for cost. We do not separate environmental costs since any that might exist seem wrapped up with the technology and at this early stage of development it is difficult or impossible to separate such impacts.

Similarly a single distribution is chosen for technological change.

INTEGRATION WITH MODEL SPECIFICATION

Both cost and technological change are specified by region in the model. Technological change is assumed to be identical across regions. Scale factors are applied to costs to account for regional variability in insolation.

POTENTIAL CORRELATION WITH OTHER VARIABLES

Among regional CIL and TECH: The specification assumes perfect correlation. This seems basically justifiable. Public policy toward solar which differs by region could reduce correlation in CIL but this seems minor compared to other uncertainties.

Between CIL and TECH: High CIL estimates tend to give more room for technological changes because of differences in assumptions about scale of facilities producing solar components in 2000, when critical breakthroughs will occur, etc. Thus, it seems justifiable to expect moderate positive correlation between CIL and TECH. On the other hand, very high correlation would imply that the technologies would certainly become economic, it was just a matter of time. This would probably be an overly optimistic assumption.

Assessed Impact: Positive correlation - moderate.

DISTRIBUTIONS

Renewable Electricity Cost in 2000

1975\$/GJ

	<u>Percentile</u>		
	<u>3</u>	<u>50</u>	<u>97</u>
Cost	6.00	25.00	200.00

Technological Change (percent per year)

	<u>Percentile</u>		
	<u>3</u>	<u>50</u>	<u>97</u>
Value	-1.0	2.5	6.0

DISAGGREGATION TO MODEL REGIONS

The following regional factors are applied to CIL based on electricity cost variation due to variance in insolation.

<u>Region</u>	<u>Scale Factor</u>	<u>Region</u>	<u>Scale Factor</u>
U.S.	1.19	Centrally Planned Asia	1.59
OECD WEST	1.70	Middle East	1.00
JANZ	1.37	Africa	1.03
Centrally Planned Europe	1.70	Latin America	1.59
		South & East Asia	1.22

From Reilly et al. (1983), p. 288. TECH is assumed to apply directly to all regions.

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 WORKSHEET

The main limiting factor is seen as the technological aspects rather than higher cost resource grades. Since the energy is renewable it would mean moving to poorer quality resources after utilizing the best locations. While there are valid arguments for insolation to vary from area to area (e.g., nearness to equator, cloudiness, etc.) within regions, the major long-term factor seems to be the basic technological cost of solar collectors. Moreover, areas with poor insolation may have high quality wind energy resources, OTEC potential, or other sources. Total global insolation, apart from other technologies, offers no binding resource constraint; the limiting constraint is the cost (efficiency) with which solar energy can be converted to usable forms.

The table below lists some estimates of the cost of solar in the year 2000 in 1979 dollars per GJ.

Cost of Electricity from Renewable Sources Projected for Year 2000
(1979\$/GJ)

	<u>Photovoltaic</u>	<u>STEC*</u>	<u>WIND</u>
EIA/DOE	22.20		14.45
Bennington	13.05-31.65	9.45-43.60	10.75
SRI	19.85-22.80	31.94-44.16	10.47
CONAES	20.00-144.40	18.05-27.22	7.60-49.45

*Solar Thermal Electric Conversion

Note: Convert to 1975\$ by multiplying by .781.

Source: Reilly et al., 1983, p. 271, p. 283, p. 302.

These costs are assumed to be for areas of relatively high insolation (e.g., U.S. Southern California, or Middle East, Northern Africa). Because of the very different technologies we set only a mid-point and extremes for the distribution.

Technological Change

Considerable Technological advance is seen as occurring between now and 2000. However the rates are seen as slowing after 2000 in most studies. This reflects the early stage of solar development. Less technological change is forecast for wind energy because the technology is better known. Similarly, STEC technologies are based on components which are fairly well-known. The table below contrasts estimates of technological improvement.

Reductions in Cost Due to Improvements in Technology and Production

	(% year)	
<u>STEC</u>	<u>To 2000</u>	<u>After 2000</u>
Bennington	2.5	2.8-4.5
SRI	-	1.6
CONAES	8.9	2.10
SRI	7.1	-
<u>Photovoltaics</u>		
Bennington	23.7-27.2	.9-2.8
SRI	8.2	-
CONAES	6.6-12.0	7.8
A. D. Little	16.4	-

Since we are not separating "environmental costs," we might consider the possibility of negative improvement after 2000 to account for increasing costs of land, etc.

INPUT ASSUMPTION

Solids to Liquids and Gas Transformation

NUMBER OF MONTE CARLO VARIABLES

2

VARIABLES INVOLVED

HCILT2, GCI

DATA FORMAT FOR MONTE CARLO ANALYSIS

HCILT2 is the capital cost of synfuel production. GCI is the inverse of the efficiency with which the solid fuel is converted to liquids or gases (the multiplicative factor which determines the of costs of a unit of synfuel production owing only to the coal or biomass used to produce it). Costs and efficiencies are those assumed to hold when the technology is relatively mature. A single distribution is chosen for each.

INTEGRATION WITH MODEL SPECIFICATION

HCILT2 is region specific in the model. A single value is chosen for the world for each run and is assumed to apply in all regions. Since syngas and synoil production are similar processes, the value of the syngas HCILT2 is assumed to be a fixed proportion (.73) of the synoil value. The same GCI value is assumed to hold for both synoil and syngas.

POTENTIAL CORRELATION WITH OTHER VARIABLES

We see no obvious correlation with other variables.

DISTRIBUTIONS

HCILT2 (1975\$/gj of Synfuel Produced)

	Percentile				
	<u>3</u>	<u>16</u>	<u>50</u>	<u>84</u>	<u>97</u>
Value	3.50	4.00	4.50	10.00	20.00

	<u>GCI</u>		
	<u>3</u>	<u>50</u>	<u>97</u>
Value	1.25	2.00	3.30

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WORKSHEET

The following two tables show estimated costs of synfuels. Most of the synoil costs assume that the plant will be situated near a cheap source of coal, thus coal will be available at \$10 (1979\$) per ton or less. As the syngas table shows, assuming a 38 percent conversion factor the fuel cost is then on the order of $1/.38 \times \$.36$ (1979\$) = \$.95 per 10^6 Btus of fuel produced or converting to 1975 dollars per GJ = \$.70.

Synoil from Coal Costs

<u>Source/Year</u>	<u>Cost (1979\$/barrel of oil equivalent</u>	<u>1975\$/GJ</u>
NAS/1977	28-48	3.60-6.10
IGT/1978	34	4.35
AGA/1979	44	5.60
Booz-Allen/1979	29-35	3.70-4.50
Cameron Engineers/1979	29-38	3.70-4.85
U.S. DOE/1979	25-32	3.19-4.10
EPRI/1979	33	4.20
ESCOE/1979	28	3.60
AERG/1979	22-32	2.80-4.10
CRS/1980	29-41	3.70-5.25
IIASA/1981	32	4.10

Source: Reilly et al. (1983), p. 96.

Illustrative Costs of Coal Gas^a

<u>Coal Input Cost (1979\$)</u>		<u>"Barebones" Selling Price 1975\$/GJ</u>
<u>Dollars/Metric Ton Coal Equivalent</u>	<u>Dollars/10⁶ Btus</u>	
5	.18	4.49 - 6.07
10	.36	4.84 - 6.42
15	.54	5.20 - 6.78
20	.72	5.54 - 7.12
30	1.08	6.24 - 7.83
60	2.16	8.35 - 9.93

^aCalculated using revenue requirement method assuming an 8 and 15 percent real return straight line depreciation, total capital cost of \$2,984 (1979\$) million plant producing $.295 \times 10^{12}$ Btus per day, 330 operating days per year, 25 year life, and operating costs (minus feestock) of \$186.8 (1979\$) million per year. Based on data in Shackson and Leach, Using Fuel Economy and Synthetic Fuels to Compete with OPEC Oil, Mellon Institute, Arlington, Virginia, 1980. The plant description allows for production of methanol or methane or a combination. Capital costs per GJ in 2975 dollars output are 4.30 (15 percent real return) and 2.72 (8 percent real return), operating and maintenance costs (1975\$) are 1.42 per GJ of output. Coal is converted into gas at a 38 percent overall thermal efficiency.

Source: Reilly et al. 1983, p. 186.

These costs only take into account a minimum of pollution control. As the scale of synoil production expands pollution control may prove costly or the plants may face siting problems which limit the amount produced or make plants more expensive. In addition, there may be problems with further transforming the liquids to the equivalent of crude products, e.g., gasoline. Thus, costs could be considerably higher. However, efficiencies of conversion could improve.

INPUT ASSUMPTION

Hydroelectricity Resource Base

NUMBER OF MONTE CARLO VARIABLES

1

VARIABLES INVOLVED

RESIL

DATA FORMAT FOR MONTE CARLO ANALYSIS

Total global economic resource in exajoules.

INTEGRATION WITH MODEL SPECIFICATION

In the model resources are specified by region. Regional values are deterministically linked to the global total.

POTENTIAL CORRELATION WITH OTHER VARIABLES

None

DISTRIBUTIONS

	Percentile		
	3	50	97
Resource Amount in EJ(e)/yr	8.00	26	45

Discussion. The major source of hydro power estimates is the WEC, 1978. However, because of the method of estimation and failure to "adequately" consider limits to hydro because of environmental constraints and competing

uses of land flooded by hydro dams, many researchers today consider the WEC estimates to be high. However, no major effort to repeat the exercise of estimating hydro resources has been attempted to date. Reilly et al., 1983 (p. 315) list the WEC recoverable estimate to be 37.26 EJ. We take the 50 percentile value to be 70 percent of this figure. For the 3 percentile value we take the WEC estimate of operating capacity expected to be in place by 1985 (Reilly et al., p. 318). For the 97 percentile we assume that the full amount of the WEC estimate plus 20 percent is exploitable.

DISAGGREGATION TO MODEL REGIONS

<u>Region</u>	<u>Fraction</u>
USA	.062
WEUR & CAN	.125
OECD PAC	.027
EUSSR	.134
ACENP	.155
MIDEAST	.016
AFR	.196
LA	.174
SEASIA	.112

Based on Reilly et al. (1983) recoverable resources by region, p. 318.

INPUT ASSUMPTION

Nonfuel costs of electricity production from coal.

NUMBER OF MONTE CARLO VARIABLES

1

VARIABLES INVOLVED

HUIL (coal)

DATA FORMAT FOR MONTE CARLO ANALYSIS

Capital cost of electricity production for coal per gj of electricity produced.

INTEGRATION WITH MODEL SPECIFICATION

Format is the same as specified disaggregated by region.

POTENTIAL CORRELATION WITH OTHER VARIABLES

None

DISTRIBUTIONS

	Percentile		
	<u>3</u>	<u>50</u>	<u>97</u>
Cost 1975\$/gj of Electricity Produced	6.50	6.90	14.00

Discussion. The assessed, 1975 cost in OECD regions was \$6.86. We do not believe these costs are likely to fall but we allow for a possible doubling because of environmental effects.

DISAGGREGATION TO MODEL REGIONS

Multiplier

OECD Regions (i.e., 1-3)	1.00
All other regions (4-9)	.85

Capital costs are assumed lower in non-OECD regions because of less stringent environmental controls.

WHEN THE MODEL REACHES EQUILIBRIUM
THE DURATION OF THE CYCLE IN WHICH ALL REGIONS

INPUT ASSUMPTION

Biomass supply.

NUMBER OF MONTE CARLO VARIABLES

1

VARIABLES INVOLVED

BIOPSM

DATA FORMAT FOR MONTE CARLO ANALYSIS

The Monte Carlo variable is a scale parameter which shifts the supply schedule for biomass up or down.

INTEGRATION WITH MODEL SPECIFICATION

The biomass supply schedule is determined as an interpolation between pairs of price/quantity points. The scale factor is a multiplier of the price in each price/quantity point. The schedules are regionalized in the model but the same price modes apply for all regions. Thus, the scale factor is assumed to apply identically to all price modes for all regions.

POTENTIAL CORRELATION WITH OTHER VARIABLES

Correlation with population and productivity might be expected due to competing demands for land for food, recreation, forestry, as population and income increase. Assessed Impact moderate to strong.

DISTRIBUTIONS

	Percentile
3	50
2	1.0
	4.0

 

APPENDIX B

THE IEA/ORAU LONG-TERM GLOBAL ENERGY-CO MODEL VERSION A.84--MODEL IMPROVEMENTS

The IEA/ORAU Long-Term Global Energy-CO Model was originally developed in 1982 in support of work conducted for the U.S. Department of Energy Carbon Dioxide Research Division in the area of future global fossil fuel related CO emissions research. This model received extensive review both internal and external (Kuenne et al., 1981; Rose et al., 1983; Ausubel and Nordhaus, 1983; and Keepin, 1984). The uncertainty analysis, documented in this report, made demands on the model that had not previously been made, and in the process of operating the model much was learned about areas in which simplification or elaboration was justified, or in which a different approach was warranted. As a consequence of these criticisms, demands, and learning numerous model modifications were undertaken.

Since two versions of the IEA/ORAU Long-Term, Global, Energy-CO model now exist, version specifications have been adopted. The 1984 version is designated A.84, while the version completed in 1982 is designated B.82.

Model changes fall into three categories, those which affect the theoretical structure of the model, those which affect the computational processes of the model, and those which affect only the mode by which model inputs are entered.

Theoretical Changes

1. Base GNP Determination
2. Fossil Fuel and Nuclear Electric Supply

Note: For references see bibliography at the end of main text.

Computational Changes

1. Energy Balance Determination
2. Search Algorithm Changes

Input Mode Changes

1. Transportation Costs and Initial Price Estimates
2. Tariffs and Taxes
3. Population and GNP
4. End-Use Energy Efficiency
5. Supply Parameters
6. Demand Parameters
7. CO Coefficients

MODEL DICTIONARY

To make it easier for the reader to follow the discussions about the computer code, we include a dictionary of variables reproduced from the Software Description contained in CDIC, 1984 (See Table B-1).

THEORETICAL CHANGES

Every attempt has been made to make this appendix self explanatory. But the very nature of the comparison exercise dictates a familiarity with the original model version, B.82. Documentation for the theoretical model structure can be found in Edmonds and Reilly, 1983 and/or CDIC, 1984 (which contains Edmonds and Reilly, 1983 as an appendix). In the discussions of theoretical material that follow, unless otherwise stated, we will reference page and equation numbers for Edmonds and Reilly, 1983 in our discussion of the theoretical structure of model version B.82.

Base GNP DeterminationOriginal Specification

$GNP_{1,t}$ = base level of economic activity for region 1 in period t (Note: An internal energy-feedback mechanism exists to modify GNP in response to energy scarcity) $GNP_{1,t}$ were exogenously specified inputs.

IV. LIST OF SUBROUTINES

1=USA
2=OECD EUROPE
3=OECD PACIFIC
4=USSR/E.EUR
5=CHINA/ET.AL.
6=MIDDLE EAST
7=AFRICA
8=LATIN AMERICA
9=S&E ASIA

TABLE B-1. DICTIONARY OF VARIABLES (Continued)

M = PERIOD INDEX

1=1975

2=2000

3=2025

4=2050

5=2075

6=2100

II. VARIABLE LIST

AIL = ON INPUT THIS PARAMETER IS THE AMOUNT OF CUMULATIVE PRODUCTION OF FUEL I IN REGION L. IT IS USED IN SUBROUTINE SSSS. IT CAN BE CONVERTED TO THE LOGISTICS PARAMETER A VIA THE TRANSFORMATION:

$$A = \text{DLOG}(\text{AIL}/\text{RESIL}-\text{AIL}).$$

AMBDA = A SCALE FACTOR USED TO ADJUST THE PRICE ADJUSTMENT COEFFICIENTS $\text{DP}(I)$ WHEN THEIR MAGNITUDES WOULD GIVE A NEGATIVE ADJUSTED PRICE

BBESIL = BASE YEAR (1975) MINIMUM ENERGY SUPPLY OF UNCONSTRAINED ENERGY TYPE I IN REGION L

BESILM = BASE ENERGY SUPPLY OF UNCONSTRAINED ENERGY TYPE I, FOR REGION L, IN PERIOD M SPECIFIED AT A REFERENCE PRICE. (THE BREAKTHROUGH PRICE, AIL TIMES A SCALAR DILSET)

BIL = YEAR OF PEAK PRODUCTION FOR FUEL I (OIL OR GAS) IN REGION L. IT IS TRANSFORMED TO THE LOGISTICS CURVE PARAMETER B, EQUAL TO $-A/T$, WHERE A IS COMPUTED FROM THE INPUT PARAMETER AIL AND T IS THE DATE OF MAXIMUM PRODUCTION.

BIOLM = THE RESOURCE BASE FOR COMMERCIAL BIOMASS IN REGION L FROM MODE IM

IM=1 URBAN AND RURAL WASTES--THESE ARE PROPORTIONAL TO GNP

IM=2 CULTIVATED BIOMASS

BIOPSM = BIOMASS SUPPLY SCHEDULE PARAMETERS

IP = NUMBER OF CRITICAL POINTS AT WHICH THE SLOPE OF THE SUPPLY SCHEDULE SHIFTS

IS = CRITICAL PRICE (IS=1) OR SHARE OF RESOURCE UTILIZED AT THAT PRICE (IS=2)

IM = MODE (SEE BIOLM)

BPSL = BASE YEAR AGGREGATE ENERGY SERVICE PRICE FOR REGION L

BPKL = BASE YEAR ENERGY SERVICE PRICE FOR SECTOR K IN REGION L

BSCIL = BASE SHARE OF COAL IN SYN FUEL MARKET

BSJKLM = BASE SHARE OF SECTOR K ENERGY SERVICES IN REGION L PROVIDED BY SECONDARY ENERGY TYPE J IN PERIOD M

BSKL = BASE EQUAL TO THE TOTAL ENERGY SERVICES PROVIDED BY SECTOR K IN REGION L

BSUILM = BASE SHARE OF ELECTRICITY GENERATED BY FUEL I IN REGION L AND PERIOD M IF ALL GENERATING PRICES WERE EQUAL

CEFLM = $\text{CONM} + \text{EFL}$ = CONSERVATION AND NONELECTRIC SOLAR PLUS SECONDARY FUELS IN REGION L FOR PERIOD M

CEFM = $\text{CONM} + \text{EF}$ = CONSERVATION AND NON-ELECTRIC SOLAR PLUS SECONDARY FUELS FOR PERIOD M

CIL = BREAKTHROUGH COST FOR BACKSTOP FUEL I IN REGION L.

TABLE B-1. DICTIONARY OF VARIABLES (Continued)

THIS VARIABLE IS DERIVED USING THE INFORMATION
 CARRIED BY VARIABLE CILT PLUS THE YEAR IN WHICH
 THE SCENARIO IS BEING CONSTRUCTED. CIL APPEARS
 IN SUBROUTINE SSSS.

CILT = BREAKTHROUGH COST VARIABLES FOR BACKSTOP FUEL I
 IN REGION L
 T=1 INITIAL PERIOD BREAKTHROUGH PRICE
 T=2 ULTIMATE BREAKTHROUGH PRICE
 T=3 NUMBER OF PERIODS OF TRANSITION

CO2IL = CARBON EMISSIONS FROM SOURCE I IN REGION L
 I=1 OIL CONSUMPTION
 I=2 GAS CONSUMPTION
 I=3 COAL CONSUMPTION
 I=4 SHALE OIL PRODUCTION
 I=5 COAL LIQUIFICATION
 I=6 COAL GASIFICATION
 I=7 BIOMASS ABSORPTIONS
 I=8 GAS FLARING

CO2IM = GLOBAL CARBON EMISSIONS FROM SOURCE I IN PERIOD M
 CO2LM = TOTAL CARBON EMISSIONS FROM ALL SOURCES IN REGION L
 IN PERIOD M

CO2M = TOTAL GLOBAL CARBON EMISSIONS FROM ALL SOURCES IN PERIOD M
 CONLM = CONSERVATION AND NON-ELECTRIC SOLAR ENERGY IN REGION L,
 COI = RATE OF CARBON EMISSIONS PER EXAJoule OF SECONDARY FUEL I
 CONM = TOTAL CONSERVATION AND NON-ELECTRIC SOLAR ENERGY FOR
 PERIOD M

OIL = REFERENCE PRICE ASSOCIATED WITH THE BASE OUTPUT LEVEL
 BESILM FOR BACKSTOP TECHNOLOGY I IN REGION L
 OILSET = SCALE FACTOR RELATING THE REFERENCE PRICE (OIL IN THE
 THEORETICAL VOLUME) TO THE BREAKTHROUGH PRICE CIL
 EASTIM = EXOGENOUSLY SPECIFIED LEVELS OF MIDEAST OIL AND GAS
 PRODUCT FOR PERIOD M. NOTE, THESE OVERRIDE OUTPUT OF THE
 LOGISTICS CURVES FOR THE MIDEAST.

EDM = TOTAL GLOBAL PRIMARY ENERGY DEMAND IN PERIOD M
 OF THE LOGISTICS CURVES FOR THE MIDEAST.

EDIM = TOTAL DEMAND FOR PRIMARY ENERGY TYPE I BY ALL REGIONS
 IN PERIOD M

EDIKL = TOTAL DEMAND FOR PRIMARY ENERGY TYPE I BY SECTOR KK
 IN REGION L

EDIL = TOTAL DEMAND FOR PRIMARY ENERGY TYPE I BY REGION L
 EDIMKT = TOTAL DEMAND FOR ENERGY IN WORLD MARKET I
 EDJKL = DEMAND FOR SECONDARY FUEL TYPE J BY SECTOR KK IN REGION L
 EDKL = TOTAL DEMAND FOR PRIMARY ENERGY BY SECTOR K IN REGION L
 EDLM = TOTAL DEMAND FOR PRIMARY ENERGY BY REGION L, PERIOD M
 EDRIKL = TOTAL DEMAND FOR REFINABLE FUEL I (PRIMARY ENERGY AFTER
 SYN FUEL CONVERSIONS OF COAL) BY SECTOR KK IN REGION L

EDRM = TOTAL DEMAND FOR REFINABLE FUELS IN PERIOD M
 EDRKM = TOTAL DEMAND FOR REFINABLE FUELS BY THE ELECTRIC UTILITY
 SECTOR IN PERIOD M

EDRIKM = TOTAL DEMAND FOR REFINABLE FUEL I BY THE ELECTRIC
 UTILITY SECTOR IN PERIOD M

EDRIL = TOTAL DEMAND FOR REFINABLE FUEL I IN REGION L
 EDRIM = TOTAL DEMAND FOR REFINABLE FUEL I IN PERIOD M
 EDRKLM = TOTAL DEMAND FOR REFINABLE FUELS IN SECTOR K IN REGION L
 IN PERIOD M

TABLE B-1. DICTIONARY OF VARIABLES (Continued)

C	EDRLM =	TOTAL DEMAND FOR REFINABLE FUELS IN REGION L IN PERIOD M
C	EFM =	TOTAL DEMAND FOR SECONDARY FUELS IN ALL REGIONS, PERIOD M
C	EFJM =	TOTAL DEMAND FOR SECONDARY FUEL TYPE J BY ALL REGIONS
C		IN PERIOD M
C	EFJKL =	TOTAL DEMAND FOR SECONDARY FUEL TYPE J BY SECTOR KK
C		IN REGION L
C	EFJL =	TOTAL DEMAND FOR SECONDARY FUEL TYPE J IN REGION L
C	EFKL =	TOTAL DEMAND FOR SECONDARY FUELS BY SECTOR K IN REGION L
C	EFLM =	TOTAL DEMAND FOR SECONDARY FUELS IN REGION L IN PERIOD M
C	EPCLM =	ENERGY USE IN BILLIONS OF JOULE PER CAPITA IN REGION L
C		IN PERIOD M
C	EPGLM =	ENERGY USE IN MILLIONS OF JOULES PER 1975 US DOLLAR OF
C		OF GNP IN REGION L IN PERIOD M
C	ESM =	TOTAL SUPPLY OF PRIMARY ENERGY BY ALL REGIONS IN PERIOD M
C	ESIM =	TOTAL SUPPLY OF PRIMARY ENERGY TYPE I BY ALL REGIONS
C		IN PERIOD M
C	ESI1M =	ESIL1 SUMMED OVER I IN PERIOD M
C	ESI2M =	ESIL2 SUMMED OVER I (TOTAL ESIL2 IN REGION L) IN PERIOD M
C	ESIL =	SUPPLY OF PRIMARY ENERGY TYPE I IN REGION L
C	ESIL1M =	ENERGY SUPPLY FROM CONVENTIONAL SOURCES FOR EXHAUSTABLE
C		FOSSIL FUEL I (OIL OR GAS) OR BIOMASS IN PERIOD M
C	ESIL2M =	ENERGY SUPPLY FROM UNCONVENTIONAL SOURCES OF EXHAUSTABLE
C		FOSSIL FUELS (OIL & GAS) PLUS BIOMASS IN PERIOD M
C	ESIMKT =	TOTAL ENERGY SUPPLY IN WORLD MARKET I
C	ESLM =	TOTAL SUPPLY OF PRIMARY ENERGY IN REGION L IN PERIOD M
C	ESL1M =	ENERGY SUPPLY FROM CONVENTIONAL SOURCES FOR EXHAUSTABLE
C		FOSSIL FUELS AND BIOMASS IN REGION L IN PERIOD M
C	ESL2M =	ENERGY SUPPLY FROM UNCONVENTIONAL SOURCES FOR EXHAUSTABLE
C		FOSSIL FUELS AND BIOMASS IN REGION L IN PERIOD M
C	ESR1LM =	TOTAL SUPPLY OF REFINABLE FUEL I AVAILABLE TO REFINERIES
C		IN REGION L IN PERIOD M
C	ESRIM =	TOTAL SUPPLY OF REFINABLE FUEL I AVAILABLE TO REFINERIES
C		IN PERIOD M
C	ESRLM =	TOTAL SUPPLY AVAILABLE TO REFINERIES IN REGION L, PERIOD M
C	ESRL1M =	REFINABLE COAL SUPPLY IN REGION L, PERIOD M
C	ESRL2M =	REFINABLE BIOMASS SUPPLY IN REGION L, PERIOD M
C	ESRM =	TOTAL SUPPLY AVAILABLE TO REFINERIES IN PERIOD M
C	ESR1M =	TOTAL REFINABLE COAL SUPPLY IN PERIOD M
C	ESR2M =	TOTAL REFINABLE BIOMASS SUPPLY IN PERIOD M
C	ESUM =	OF ELECTRICITY GENERATED IN PERIOD M
C	ESUIM =	OUTPUT OF ELECTRICITY GENERATED BY FUEL I IN PERIOD M
C	ESUIL =	OUTPUT OF ELECTRICITY GENERATED BY FUEL I IN REGION L
C	ESULM =	OUTPUT OF ELECTRICITY GENERATED IN REGION L IN PERIOD M
C	EXM =	TOTAL WORLD TRADE IN PRIMARY ENERGY IN PERIOD M
C	EXIM =	TOTAL IMPORTS OF PRIMARY ENERGY TYPE I BY ALL REGIONS
C		IN PERIOD M
C	EXIL =	TOTAL IMPORTS OF PRIMARY ENERGY TYPE I IN REGION L
C	EXLM =	TOTAL IMPORTS OF PRIMARY ENERGY IN REGION L IN PERIOD M
C	FJKL =	DEMAND FOR SECONDARY FUEL J IN SECTOR K IN REGION L
C	FJL =	TOTAL DEMAND FOR SECONDARY FUEL J IN REGION L
C	FK =	DEMAND FOR ENERGY SERVICES FROM ALL MODES IN SECTOR K
C	FLRL =	SHARE OF GAS PRODUCTION NOT MARKETING IN REGION L.
C		(FLARED OR REINJECTED)
C		FOR EACH REGION THERE ARE THREE VARIABLES:
C		FLRL=1 INITIAL FLARING RATE (MUST BE NON-ZERO)

TABLE B-1. DICTIONARY OF VARIABLES (Continued)

FLRL=2 ULTIMATE FLARING RATE (MUST BE NON-ZERO)
 FLRL=3 NUMBER OF YEARS TO REACH ULTIMATE RATE
 THE PROGRAM EXPONENTIALLY INTERPOLATES BETWEEN RATES
 OVER THE SPECIFIED NUMBER OF YEARS.
 GCI = INPUT-OUTPUT COEFFICIENT OF COAL INTO
 PRIMARY EQUIVALENT I
 GIJ = REFINERY INPUT-OUTPUT COEFFICIENT FOR PRIMARY ENERGY
 TYPE I
 GJ = ENERGY INPUT-OUTPUT COEFFICIENT OF SECONDARY FUEL J IN
 GENERAL END-USE
 GJK = ENERGY INPUT-OUTPUT COEFFICIENT OF SECONDARY FUEL J
 IN SECTOR K (OECD)
 GNP = BUSINESS-AS-USUAL GNP FOR REGION L IN PERIOD M (BASE=1.0)
 GNPBL = BASE YEAR(1975) GNP IN 1975 US DOLLARS IN REGION L
 GNPFLM= GNP IN MILLIONS OF 1975 DOLLARS IN REGION L FOR
 PERIOD M
 GNPLM = BUSINESS-AS-USUAL GNP FOR REGION L IN PERIOD M IN
 MILLIONS OF 1975 CONSTANT U.S. DOLLARS
 GNPPCM= PER CAPITA GNP IN MILLIONS OF 1975 US DOLLARS IN PERIOD M
 GUI = ELECTRIC UTILITY INPUT-OUTPUT COEFFICIENT FOR FUEL TYPE I
 HCILT = NON-ENERGY COST OF CONVERSION FROM COAL TO FUEL I IN
 REGION L:
 T=1 INITIAL PERIOD COST
 T=2 ULTIMATE COST
 T=3 NUMBER OF PERIODS OF TRANSITION
 HIJ = NON-ENERGY COSTS OF REFINING ONE JOULE OF PRIMARY FUEL I
 HJ = NON-ENERGY COST OF SECONDARY FUEL J IN GENERAL END-USE
 HJK = NON-ENERGY COST OF SECONDARY FUEL J IN SECTOR K (OECD)
 HUIL = NON-ENERGY COSTS OF PRODUCING ELECTRICITY FROM FUEL I
 IN REGION L
 HYDRO = HYDROELECTRIC ENERGY VARIABLE I IN REGION L
 I=1 LOGISTICS INTERCEPT FOR HYDRO IN REGION L
 I=2 LOGISTICS PENETRATION PARAMETER FOR HYDRO IN REGION
 I=3 RESOURCE BASE FOR HYDRO IN REGION L
 I=4 PRODUCTION PRICE OF HYDRO IN REGION L
 I=5 SHARE OF ELECTRICITY GENERATED BY HYDRO IN REGION L
 MAXAGN= THE MAXIMUM NUMBER OF ITERATIONS OF SEARCH FOR EQUILIBRIUM
 PRICES ALLOWED IN ANY ONE PERIOD
 MXHOLD= THE HOLD VARIABLE FOR OLD VALUES OF MAXAGN
 MXTRIP= NUMBER OF TIMES THAT EXPORT/IMPORT CONSISTENCY HAS BEEN
 CHECKED BY XXXX
 NAGN = COUNTS THE ITERATIONS OF SUBROUTINE REVISE REQUIRED TO
 ACHIEVE EQUILIBRIUM PRICING
 NAJUST= DECISION VARIABLE -- SET TO 1 WHEN AN EQUILIBRIUM
 IN MARKETS IS INCONSISTENT WITH INITIAL ASSUMPTIONS
 CONCERNING EXPORT(IMPORT) OF FUELS BY REGION.
 THE EXPORT/IMPORT VARIABLE NXIL IS THEN CHANGED
 APPROPRIATELY AND ANOTHER EQUILIBRIUM SOLUTION IS
 SOUGHT.
 NCATCH= LOGIC VARIABLE USED TO INDICATE WHEN AN EXPORT/IMPORT
 MATRIX, NXIL, HAS CYCLED BACK
 NCATCH=0 RECYCLING HAS OCCURED
 NCATCH=1 RECYCLING HAS NOT OCCURED
 WHEN RECYCLING OCCURES THE SEARCH FOR EQUILIBRIUM
 GOES THROUGH ONE MORE CYCLE IN WHICH ALL REGION/FUEL

TABLE B-1. DICTIONARY OF VARIABLES (Continued)

COMBINATIONS IN WHICH RECYCLING OCCURS ARE GIVEN
1/2 THE NORMAL TRANSPORT CHARGES.

NCO2 = THE NUMBER OF CARBON EMISSION SOURCE TYPES

NFAIL = DECISION VARIABLE -- SET TO 1 WHEN DEMAND AND SUPPLY ARE
NOT WITHIN TEST LIMITS

NF = NUMBER OF FOSSIL FUELS

NFF = NUMBER OF SYNFUEL TYPES

NHOLD = TEMPORARY HOLDING VARIABLE USED IN SUBROUTINE XXXX TO
RETAIN THE VALUE OF NXIL BEFORE TRANSFER TO NHXIL

NHXIL = LOGIC VARIABLE USED TO HOLD VALUES OF NXIL FROM A
PREVIOUS SEARCH ITERATION FOR COMPARISON TO VALUES
OF NXIL IN THE FOLLOWING ITERATION.

NI = NUMBER OF PRIMARY ENERGY TYPES

NIM = NUMBER OF BIOMASS MODES OR TYPES

NIP = MAXIMUM NUMBER OF PRICE-SHARE CRITICAL POINTS IN THE
BIOMASS SUPPLY SCHEDULE

NJ = NUMBER OF SECONDARY ENERGY TYPES

NJUMP = NUMBER OF YEARS BETWEEN GNP PROJECTIONS

NKKL = NUMBER OF FINAL DEMAND SECTORS PLUS UTILITIES IN REGION L

NKKMAX = MAXIMUM NUMBER OF FINAL DEMAND SECTORS PLUS UTILITIES

NKL = NUMBER OF FINAL DEMAND SECTORS IN REGION L

NKMAX = MAXIMUM NUMBER OF FINAL DEMAND SECTORS

NL = NUMBER OF REGIONS

NM = NUMBER OF PERIODS

NMKT = NUMBER OF GLOBAL ENERGY MARKETS

NMREAD = THE NUMBER OF PERIODS OF DATA CONTAINED IN THE DATA FILE
TO BE READ. THIS NEED NOT BE THE SAME AS THE NUMBER
OF FORECAST PERIODS, NM BUT MUST ALWAYS BE AT LEAST
AS LARGE AS NM.

NO = SET TO 1 IF THE PRICE ADJUSTMENT PROCESS IS NOT
AS LARGE AS NM.
DECREASING THE TOTAL VARIANCE OF ALL MARKETS'
DIVERGENCE FROM EQUILIBRIUM. IF CONVERGENCE
IS NOT OCCURRING MARKET PRICE ADJUSTMENTS
ARE REVISED. (LOCAL TO REVISE)

NOPT = OUTPUT OPTION CONTROL VARIABLE

NTIMES = COUNTER USED TO INDICATE HOW MANY TIMES THE ELASTICITY
SUBROUTINE HAS BEEN CALLED

NU = NUMBER OF COMPETING ELECTRIC UTILITY ENERGY TYPES

NUB = LOGIC VARIABLE WHICH ACTIVATES THE DEMAND MODULE
SHORTCUT DURING THE CONSERVATION CALCULATIONS
NUB = 1 SKIPS THE COMPUTATION OF
REFINABLE AND PRIMARY ENERGY

NXIL = IMPORT/EXPORT INDEX FOR FUEL I, IN REGION L
NXIL = 1 EXPORTER
NXIL = -1 IMPORTER

OLDPI = RETAINS THE OLD PRICE VALUES FOR COMPARISON WITH THE NEW
PRICE VALUES WHICH RESULT FROM EXECUTION OF 'REVISE'

OLOXI = HOLDING VARIABLE RETAINS THE OLD LEVELS OF EXCESS DEMAND
IN WORLD MARKET I

PAUIL = PRICE ADJUSTMENT SCALAR FOR FUEL PRICE I USED IN ELECTRIC
POWER PLANTS OF REGION L

PI = WORLD PRICE FOR FOSSIL FUEL TYPE I

PCIL = THE COST OF PRODUCING REFINABLE FUEL I USING SOLIDS
AS A FEEDSTOCK IN REGION L. OUTPUT FUELS ARE:

TABLE B-1. DICTIONARY OF VARIABLES (Continued)

1. LIQUIDS, 2. GASES, 3. SOLIDS
 FEEDSTOCKS ARE: 1. COAL, 2. BIOMASS.

PILM = PRICE FOR PRIMARY FUEL I IN REGION L IN PERIOD M
 PJKLM = PRICE OF ENERGY-SERVICES IN SECTOR K USING FUEL J
 IN REGION L IN PERIOD M
 PJLM = PRICE OF SECONDARY ENERGY TYPE J IN REGION L IN PERIOD M
 PKLM = PRICE OF ENERGY-SERVICES IN SECTOR K IN REGION L, PERIOD M
 PSL = PRICE OF AGGREGATE ENERGY-SERVICES IN REGION L
 PUILM = PRICE OF ELECTRICITY GENERATED WITH ENERGY TYPE I
 IN PERIOD M
 RCI = LOGIT ELASTICITY PARAMETER FOR SYNFUEL SUBSTITUTION
 AGAINST BACKSTOP TECHNOLOGY I
 RESIL = TOTAL RESOURCE OF FUEL I IN REGION L
 RIL = INITIAL SUPPLY PRICE ELASTICITY FOR BACKSTOP FUEL I IN
 REGION L
 RPJ = GENERAL SUBSTITUTION ELASTICITY FOR FUEL J (NON-OECD)
 RPJK = END-USE SUBSTITUTION ELASTICITY FOR FUEL J IN
 SECTOR K (OECD)
 RPK = GENERAL END-USE PRICE ELASTICITY OF DEMAND (NON-OECD)
 RPKK = END-USE PRICE ELASTICITY OF DEMAND FOR SECTOR K (OECD)
 RSYIL = OUTPUT ELASTICITY OF BESILM
 RUI = LOGIT ELASTICITY PARAMETER FOR FUEL TYPE I
 RY = FEED-BACK ELASTICITY OF AGGREGATE ENERGY SERVICE PRICE ON
 GNP
 RYJ = GENERAL INCOME SUBSTITUTION ELASTICITY FOR FUEL J
 RYJK = END-USE INCOME SUBSTITUTION ELASTICITY FOR FUEL J IN
 SECTOR K (OECD)
 RYKT = GENERAL END-USE INCOME ELASTICITY OF DEMAND (NON-OECD)
 T=1 FOR THE USSR (L=4)
 T=2 FOR ALL OTHER NON-OECD REGIONS (L=5-9)
 RYKK = END-USE INCOME ELASTICITY OF DEMAND FOR SECTOR K (OECD)
 RYKLT = INCOME ELASTICITY CONTROL PARAMETERS
 IT=1 INITIAL ELASTICITY
 IT=2 ULTIMATE ELASTICITY
 IT=3 NUMBER OF YEARS TO ULTIMATE ELASTICITY
 RYSHT = INCOME ELASTICITY OF BIOMASS SUPPLY
 SBURNL = THE SHARE ON NON-MARKETED NATURAL GAS FLARED IN REGION L
 IT=1 INITIAL SHARE
 IT=2 ULTIMATE SHARE
 IT=3 NUMBER OF YEARS TO ULTIMATE SHARE
 SCC = SHARE OF COAL DEMAND FOR SOLIDS
 SCIL = SHARE OF SOLIDS SUPPLIED TO SYNFUELS TYPE I IN REGION L,
 I = OIL, GAS, SOLIDS
 SFEDIL = THE SHARE OF FUEL I USED AS A FEEDSTOCK IN REGION L
 I = OIL, GAS, SOLIDS
 SFLRL = THE SHARE OF NATURAL GAS FLARED IN REGION L
 SHALE = THE SHARE OF SHALE OIL IN UNCONVENTIONAL OIL PRODUCTION
 IN REGION L
 IT=1 INITIAL SHARE
 IT=2 ULTIMATE SHARE
 IT=3 NUMBER OF YEARS TO ULTIMATE SHARE
 SJKL = SHARE OF SECONDARY ENERGY TYPE J IN SECTOR K AND REGION L
 SUIL = SHARE OF ELECTRICITY GENERATED BY FUEL I IN REGION L
 SJKLP = WEIGHT USED IN PRICE PREPROCESSOR TO COMPUTE AGGREGATE
 PRICE OF ENERGY SERVICE OVER ALL END USES. WEIGHT

TABLE B-1. DICTIONARY OF VARIABLES (Continued)

IS DEFINED FOR SECONDARY FUEL J, SECTOR K, AND REGION L.
 SYNILM = AMOUNT OF NET SYNFUEL CONVERSIONS (ESRIL-ESIL) BY FUEL
 TYPE I IN REGION L IN PERIOD M
 SYNIM = AMOUNT OF NET SYNFUEL CONVERSIONS BY FUEL TYPE I, PERIOD M
 SYNLM = AMOUNT OF NET SYNFUEL CONVERSIONS IN REGION L IN PERIOD M
 SYNM = TOTAL AMOUNT OF SYNFUEL CONVERSIONS IN PERIOD M
 TESIL = THE HEAT EQUIVALENT ENERGY CONTENT OF HYDROELECTRICITY
 PRODUCTION IN REGION L.
 TEST = CONVERGENCE TEST VARIABLE. THIS VARIABLE DEFINES THE
 MAXIMUM AMOUNT BY WHICH ANY WORLD MARKET CAN BE IN
 EXCESS DEMAND(SUPPLY) AND THE SYSTEM TO BE CONSIDERED
 IN EQUILIBRIUM
 TJKLM = TECHNOLOGICAL CHANGE PARAMETER FOR SERVICES PROVIDED BY
 FUEL J TO SECTOR K IN OECD REGION L IN PERIOD M
 TRI = TRANSPORT COST OF FOSSIL FUEL I
 TXILM = TARIFF CHARGE FOR FOSSIL FUEL I IN REGION L IN PERIOD M
 TXJLM = TAX ON FINAL CONSUMPTION BY FUEL TYPE, REGION AND PERIOD
 UIJ = WORLD MARKET DEMAND ELASTICITY FOR FUEL I AND PRICE J
 VIJ = WORLD MARKET SUPPLY ELASTICITY FOR FUEL I AND PRICE J
 X = PERCAPITA INCOME INDEX
 XHRIL = PREVIOUS PERIOD'S EXCESS DEMAND FOR REFINABLE FUEL I
 IN REGION L
 XI = EXCESS DEMAND FOR MARKET I
 XRIL = CURRENT EXCESS DEMAND FOR REFINABLE FUEL I IN REGION L
 YLM = INDEX OF GNP IN REGION L AT THE END OF PERIOD M
 ZL = BASE YEAR(1975) POPULATION FOR REGION L IN THOUSANDS
 ZLM = POPULATION FORECAST FOR REGION L IN PERIOD M (BASE=1.0)
 ZLXM = $ZL \bullet ZLM$ = POPULATION FORECAST FOR REGION L IN PERIOD
 M (IN THOUSANDS)

III. NAMING CONVENTION FOR THE COMMON BLOCKS

SOME SUBSET OF THE VARIABLES WITHIN A COMMON BLOCK APPEARS IN EACH
 SUBROUTINE INCLUDED IN THE NAME OF THE COMMON BLOCK. THE SUBROUTINE
 ARE SPECIFIED ACCORDING TO THE FOLLOWING CONVENTIONS:

C = CO2
 D = DDDD
 E = ELAS
 N = NSET
 O = POST
 P = PPPP
 R = READ
 S = SSSS
 T = PRICES
 U = OUTPUT
 V = REVISE
 X = XXXX

NOTE: THE COMMON BLOCK 'PCP' (WHICH EXPANDS TO 'PROGRAM CONTROL
 PARAMETERS') IS THE ONLY EXCEPTION TO THIS NAMING CONVENTION.
 MOST OF THE VARIABLES IN PCP APPEAR IN ALL SUBROUTINES.

Problems with the original specification. The GNP is related to population through the workage population. The model made no explicit link between population and GNP. That link was supplied by the model user. These problems were noted in model use and are also found in Ausubel and Nordhaus, 1983 (p. 162).

Response to the problem. The determination of GNP is now made endogenously using assumptions of population and of labor productivity. Exogenous GNP is replaced by the equation,

$$GNP_{1,t} = y_{1,t-1} (1+PROL_1)^{25} (POP_{t-1}/POP_{t-2})$$

where

- $y_{1,t-1}$ = GNP for region 1 in period t-1 after adjustments for energy scarcity effects.
- PROL = Rate of growth of labor productivity per year.
- $POP_{1,t}$ = Population in region 1 in period t.
- t = Period index. Note that currently periods are 25 years long.

The model specification uses the lagged population as a proxy index for the labor force. While this specification is clearly not as good as using the work age population times a participation rate, it requires no complicated age cohort tracking model to disaggregate the population component, 15 years of age and older from the total population. Lagging the population component one period was thought to be a closer approximation to the actual index because the entire population one period prior would be of work age (though the work age population will differ from the previous period population by the difference between the number of deaths in the years between periods and births during the first ten years).

The new equation structure specifies that the base GNP grows out of the previous period's realized GNP and is larger by the amount the labor force grew times the amount that labor's productivity grew.

Comments. Note that the base GNP is now time dependent and consequently the model is no longer a static equilibrium model. It now has a dynamic link between periods through the GNP.

Coding changes. In the Version B.82 GNP assumptions are read in as an index with a 1975 value of 1.0. The code and corresponding data base are displayed below:

Subroutine = READ

```

C  -----
C  -- READ IN POPULATION DATA (ZLM) --
C  -----
C      DO 45 KK=1,7
C          READ (IUNIT,1100) A
C          IF (NOPT(2).EQ.1) GO TO 45
C          WRITE(JUNIT,2100) A
C 45 CONTINUE
C
C      DO 50 L=1,NL
C          READ (IUNIT,1031) ZL(L),(ZLM(L,M),M=1,NMREAD),ANOTE
C          IF (NOPT(2).EQ.1) GO TO 50
C          WRITE(JUNIT,2032) ZL(L),(ZLM(L,M),M=1,NMREAD),ANOTE
C 50 CONTINUE
C
C      DO 55 KK=1,8
C          READ (IUNIT,1100) A
C          IF (NOPT(2).EQ.1) GO TO 55
C          WRITE(JUNIT,2100) A
C 55 CONTINUE
C
C  -----
C  -- READ IN LABOR PRODUCTIVITY GROWTH AND --
C  -- BASE LEVEL OF GNP --
C  -----
C      DO 60 L=1,NL
C          READ (IUNIT,1040) PROL(L),GNPBL(L),NOTES
C          IF (NOPT(2).EQ.1) GO TO 60
C          WRITE(JUNIT,2040) PROL(L),GNPBL(L),NOTES
C 60 CONTINUE

```

Corresponding data elements

DATA SET = CASE B

POPULATION (ZLM) AND BASE ECONOMIC ACTIVITY (GNP)
 (POPULATION AND GNP ARE READ IN AS AN INDEX, 1975=1.00)

UNITED STATES		OECD REGIONS WEUR+CAN		OECD PACIFIC		YEAR
POPULATION	GNP	POPULATION	GNP	POPULATION	GNP	
1.000	1.000	1.000	1.000	1.000	1.000	1975
1.189	1.877	1.176	1.978	1.201	2.701	2000
1.317	3.021	1.303	3.534	1.279	5.432	2025
1.347	4.505	1.365	5.709	1.305	9.121	2050
1.3664	6.699	1.3872	8.490	1.3176	13.234	2075
1.3664	9.720	1.3872	12.318	1.3176	19.202	2100

CENTRALLY PLANNED AND MIDDLE EAST REGIONS

EUSSR		ACENPL		MIDEAST		YEAR
POPULATION	GNP	POPULATION	GNP	POPULATION	GNP	
1.000	1.000	1.000	1.000	1.000	1.000	1975
1.196	1.815	1.370	2.665	1.803	3.649	2000
1.308	2.943	1.645	5.468	2.448	8.959	2025
1.351	4.442	1.770	10.335	2.847	18.044	2050
1.372	6.606	1.8081	17.376	2.9595	30.337	2075
1.372	9.585	1.8081	28.507	2.9595	49.771	2100

DEVELOPING COUNTRY REGIONS

AFRICA		LATIN AMERICA		SOUTH & EAST ASIA		YEAR
POPULATION	GNP	POPULATION	GNP	POPULATION	GNP	
1.000	1.000	1.000	1.000	1.000	1.000	1975
1.745	3.069	1.728	3.475	1.685	3.079	2000
2.361	7.327	2.298	9.005	2.226	7.169	2025
2.758	13.806	2.631	16.395	2.556	13.502	2050
2.8807	23.787	2.7144	28.248	2.6504	23.263	2075
2.8807	39.025	2.7144	46.343	2.6504	38.166	2100

In model Version A.84 a new smaller data file is accessed consisting of population data (both historical to 1950 and forecasts to 2100) and labor productivity growth assumptions.

```

C      -----
C      -- READ IN POPULATION DATA (ZLM) --
C      -----
C      DO 45 KK=1,7
C          READ (IUNIT,1100) A
C          IF (NOPT(2).EQ.1) GO TO 45
C          WRITE(JUNIT,2100) A
C      45 CONTINUE
C
C      DO 50 L=1,NL
C          READ (IUNIT,1031) ZL(L),(ZLM(L,M),M=1,NMREAD),ANOTE
C          IF (NOPT(2).EQ.1) GO TO 50
C          WRITE(JUNIT,2032) ZL(L),(ZLM(L,M),M=1,NMREAD),ANOTE
C      50 CONTINUE
C
C      DO 55 KK=1,8
C          READ (IUNIT,1100) A
C          IF (NOPT(2).EQ.1) GO TO 55
C          WRITE(JUNIT,2100) A
C      55 CONTINUE
C
C      -----
C      -- READ IN LABOR PRODUCTIVITY GROWTH AND --
C      -- BASE LEVEL OF GNP --
C      -----
C      DO 60 L=1,NL
C          READ (IUNIT,1040) PROL(L),GNPBL(L),NOTES
C          IF (NOPT(2).EQ.1) GO TO 60
C          WRITE(JUNIT,2040) PROL(L),GNPBL(L),NOTES
C      60 CONTINUE

```


One new variable was added and the units, and magnitude of ZLM and ZL were changed as follows:

ZLM = Population forecast for region L in period M
(units = thousands of persons)
ZL = Population for region L in 1950
(units = thousands of persons)
new PROL = Rate of growth of labor productivity over the
all forecast periods (units = none)

The corresponding data elements now appear as follows:

DATASET = DATA A (uncertainty analysis median values)

POPULATION (ZLM) UNITS=THOUSANDS OF PERSONS							
1950	1975	2000	2025	2050	2075	2100	
152271.	214000.	254000.	282000.	288000.	292000.	292000.	USA
307245.	405000.	476000.	528000.	553000.	562000.	562000.	CAN&WEU
96307.	128000.	154000.	164000.	167000.	169000.	169000.	JANZ
286136.	395000.	472000.	516000.	533000.	541000.	541000.	EUSSR
590509.	911000.	1248000.	1499000.	1612000.	1647000.	1647000.	ASENP
39048.	81000.	147000.	199000.	232000.	241000.	241000.	MIDEAST
222039.	309000.	697000.	943000.	1101000.	1150000.	1150000.	AFR
165764.	313000.	540000.	718000.	823000.	849000.	849000.	LA
652760.	1130000.	1904000.	2515000.	2888000.	2995000.	2995000.	SEASIA

LABOR PRODUCTIVITY GROWTH RATE (UNITS=ANNUAL RATE)
AND BASE GNP (UNITS=MILLIONS 1975 US DOLLARS)

LABOR PRODUCTIVITY	BASE GNP	
C.C17	1519890.	USA
C.C17	1817860.	WEURECAN
C.C17	586400.	JANZ
C.C17	966400.	EUSSR
C.C29	323600.	ASENP
C.C29	138410.	MIDEAST
C.C29	154690.	AFR
C.C29	315490.	LA
C.C29	233620.	SEASIA

Base GNP is calculated in the following code:

SUBROUTINE = PSPS (a new subroutine which contains the base GNP module as well as the code which was previously found in PPPP, where energy service prices were calculated)

```

-----
--  COMPUTE BASE GNP FOR ALL REGIONS  --
-----
--  INITIALIZE BASE GNP TO 1 FOR  --
--  THE BASE PERIOD  --
-----
IF (M .EQ. 1)  YLM(L,M)=1.00
IF (M .EQ. 1)  GNP(L,M)=1.00
IF (M .EQ. 1)  GO TO 130
-----
--  FOR NON-BASE YEARS  --
--  1) COMPUTE ACTUAL LABOR PRO-  --
--  DUCTIVITY FOR PREVIOUS  --
--  PERIOD  --
--  2) COMPUTE BASE LABOR PRO-  --
--  DUCTIVITY FOR PREVIOUS  --
--  PERIOD  --
--  3) COMPUTE BASE GNP FOR CUR-  --
--  ENT PERIOD  --
-----
IF (M .EQ. 2)  GNP(L,M)=YLM(L,MM1)*(1.00+PROL(L))*NJUMP*
& (ZLM(L,MM1)/ZL(L))
IF (M .EQ. 2)  GO TO 120
& GNP(L,M)=(ZLM(L,MM1)/ZLM(L,MM2))*(1.00+PROL(L))*NJUMP*
& YLM(L,MM1)
120 CONTINUE

```

NOTE:

MM1 = M-1

MM2 = M-2

Go to 30 causes the program to skip over both the GNP estimation and the GNP feedback in the base year, which is initialized at 1.0 for all regions for the year 1975.

Fossil Fuel and Nuclear Electric Supply

Energy supply was originally disaggregated into three alternative classes:

- Class 1. Resource Constrained Conventional Energy
- Class 2. Resource Constrained Renewable Energy
- Class 3. Unconstrained Energy Resources

Conventional oil and gas were treated as Class 1 supply technologies, while unconventional oil and gas, coal, solar, and nuclear were treated as Class 3 technologies. All of the Class 1 and Class 3 (excluding solar) have been reaggregated into a new category: resource related supply technologies and are handled alike (excepting nuclear, which is handled specially).

Original Specification. Conventional oil and gas (but not coal) was given by a simple logistics equation,

$$Q_s(t) = \frac{e^{a+bt}}{(1+e^{a+bt^2})} bR$$

where

- a,b = constant parameters,
- R = total resource available,
- $Q_s(t)$ = supply per year in t, and
- t = date.

The parameters a and b were not entered directly. What was entered was

$AIL(I,L)$ = Cumulative production of fossil fuel I in region L.

$BIL(I,L)$ = Year of peak production for fuel I in region L.

These were converted to the parameters a and b via the transformations:

$$a = DLOG(AIL/(RESIL-AIL))$$

$$b = a/(1975-BIL)$$

where a is carried by TEMP and b by TENT.

The mathematics for the above transformations is as follows. In the initial period, cumulative production equals $Q(0)$, where

$$Q(0) = RESIL * \exp(AIL)/[1+\exp(AIL)].$$

If cumulative production to the period $t=0$ is given by $Q(0)$, then the value of AIL can be derived from that and RESIL via,

$$AIL = \ln Q(0)/[RESIL-Q(0)]$$

The variable BIL is handled similarly. It is entered as the year of peak production, but transformed to the logistics curve variable immediately. By differentiating the production rate with respect to t and then setting that derivative to zero, a critical (and in fact maximum) point can be determined by looking at the first order conditions which require that

$$AIL + BIL * t = 0$$

If BIL is read in as the year of maximum production, T, then it is converted by the equation

$$BIL = AIL / (T - 1975.D0)$$

with the 1975 subtracted to make t=0 in that year.

Note that for region 6 (L=6=Mideast), logistics curve parameters are overridden by the exogenously specified amounts given in the D0 215 loop for each forecast period.

For oil and gas the subroutine first transferred unconventional production from ESIL to the ESIL2M storage location. Next it took the MIDEAST (L=6), production as given and assigned conventional production to the ESIL1M variable and then branched to the end of the fuel D0 loop (statement 70). The supply of conventional oil and gas for non-MIDEAST regions was accomplished using a temporary variable, D, to first hold $\exp(a+bt)$, and then

$$\frac{be^{a+bt}}{(1+e^{a+bt})^2} bR$$

```

C
C      -- CONSIDER CONVENTIONAL FOSSIL FUELS -- NOTE MIDEAST IS
C      SPECIFIED EXOGENOUSLY
C
C      DO 70 I=1,NFF
C          ESIL2M(I,L,M)=ESIL(I,L)
C          IF (L.EQ. 6) ESIL1M(I,L,M)=EASTIM(I,M)
C          IF (L.EQ. 6) GO TO 70
C          TEMP=DLOG(AIL(I,L)/(RESIL(I,L)-AIL(I,L)))
C          TENT=TEMP/(1975.D0-BIL(I,L))
C          D=DEXP(TEMP+TENT*T)
C          D=TENT*D/(1.D0+D)**2
C          ESIL1M(I,L,M)=D*RESIL(I,L)
C      70 CONTINUE
C      80 CONTINUE

```

This completed the determination of fossil fuel energy supplies.

Unconstrained Fossil Fuel Supply

The rate of supply of unconstrained fossil fuels was given by the equation,

$$Q_t = Q^* [\ln(P/a) / \ln(P^*/a)]^{E^* \ln(P^*/a)}$$

where:

Q_t = total supply per year in period t ,
 Q^* = a base rate of production,
 P = price of output in period t ,
 P^* = a reference price,
 a = breakthrough or shut-down price,
 E^* = price elasticity of supply at $P=P^*$.

In the data set parameters were given the following assignments:

BESILM = Q^*
 CIL = a ,
 DILSET = P^*/a ,
 RIL = E^* ,
 ESIL = Q_t .

The subroutine determined total demand by first computing CIL from the information given in CILT, the number or elapsed years, T , and the interpolation subfunction. The period's CIL was then compared to the current price for fuel I . If PILM exceeded CIL, the breakthrough price, then the supply schedule was consulted (the subroutine branched to statement 45). If PILM was less than or equal to CIL, then output was zero and the supply schedule was skipped (the subroutine branched to statement 60).

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eq:

$$\text{TEMP} = \ln (P^*/a) = \ln (\text{DILSET})$$

$$\text{TENT} = \ln (p/a) = \ln (\text{PILM/CIL})$$

C
C
C
C

Problems with the original specification. Two problems were identified. For the Class 1 supply technologies there was no response to price included in the specification. Supply of these fuels was determined exogenously. The reason this specification was chosen was that in terms of the CO₂ problem, the pools of carbon represented were relatively small, and were producible at 1975 prices. Thus there was little need to model those technologies in a more sophisticated manner since these amounts of carbon were certain to be produced over the next 100 years as long as price remained above their 1975 levels. The only problem with this specification was that in some very low energy scenarios, prices dropped below 1975 levels and the basic underlying assumption of the model structure was violated. This caused other problems too. For example, in such cases the model had difficulty equating supply and demand because supply could not respond to the low prices and therefore needed to approach zero in some cases. In addition that specification put an effective floor under energy production and use. Rose et al. (1983, p. 42) makes this criticism.

The Class 3 supply description has been criticized by both Reister (1984, p. A-14) and Rose et al. (1983, p. 41) for determining the model's solution. Similarly, Rotty and Masters (1985, p. 31-32) have argued that fossil fuel resources and their geographic distribution provide a constraint on the introduction rate of carbon into the atmosphere.

Response to the problem. The response to this problem was to develop a common, resource based foundation for the analysis of all fossil fuels and nuclear power. This includes all Class 1 and 3 supply technologies with the exceptions of solar and biomass (which are handled as before).

In the revised supply module there are now

- Type 1. Resource constrained nonrenewable technologies (conventional and unconventional oil, conventional and nonconventional gas, coal, and nuclear).
- Type 2. Resource constrained renewable technologies (hydro and biomass).
- Type 3. Backstop technologies (solar)

Each type 1 of supply technology has a resource, R , which is subdivided into five grades R_g . Each grade has a minimum technical extraction cost at which it will come into production, T_g , with a maximum extraction cost T_c for all resource grades. The increase in cost between one grade and the next is assumed to be proportional to the resource in that grade consumed. The actual extraction cost, C , is the sum of both technical extraction costs, T , and environmental costs, V . These costs in turn are reduced over time by technological change, $TECH$.

$$C = (T+V)/TECH$$

Cumulative production of the resource, Q , is computed by setting the regional price of the energy type, P equal to extraction costs in Figure B-1.

Figure B-1. Graphical Representation of the Determination of Cumulative Production by Price

Production of the resource is simply the difference between Q and the previous period's cumulative production Q_{-1} . The annual production rate is equal to $(Q - Q_{-1})$ divided by the number of years per period (25).

In some cases there are extremely large resource bases available at costs above certain levels. At prices above that level the economically producible resource could be extremely large, implying rapid expansion in the rate of production.

But an industry such as shale oil cannot materialize as a mature sector over night. For a sector to grow rapidly, resources need to be pulled from other parts of the economy to provide the new capacity. Bidding these resources away from the rest of the economy results in the incursion of higher costs. To model this phenomenon we have allowed each energy technology to expand at the same rate as the GNP without penalty. Greater rates of expansion are possible but only at higher costs. If the constraint is binding, that is, if total energy production implied by the resource constrained approach implies a rate of growth of energy production greater than that of the GNP, then production is constrained to be equal to

$$E_t = E_{t-1}(Y_t/Y_{t-1})(P_t/P_{t-1})^r.$$

Nuclear power production uses the same equation structure but encounters special problems. Because all fossil fuels are traded in an open world market, the problem faced in modeling supply is one of determining the quantity of the resource supplied given a price. Nuclear power is not currently a traded fuel in the model. As currently modeled, the electric utility sector builds power plants based on the cost of production. To determine the cost of production, however, requires that the level of

resource depletion be known. To break through this dilemma, we have obtained a resource cost of uranium using a resource base and an estimate of the cumulative production. This cost is then used by the model to determine the amount of nuclear power to install, which in turn is used to determine the amount of the uranium resource base actually consumed.

Computer code. The following variables are encountered in the program:

B	= GNP constrained level of production.
BESIL	= minimum base level of production when a technology first comes into production, disaggregated by fuel type and region
C	= cost of production
CIGIS	= technological cost of extraction of an energy type disaggregated by resource and supply type
E	= holding variable for energy production
EHOLD	= holding variable
ESFIL	= production levels for 1975 disaggregated by fuel and region
ESIL	= total energy supply disaggregated by the six primary fuel types and by region
IG	= resource grade index
IG1	= IG-1
IG2	= IG-2
IS	= energy supply category 1 = conventional oil 2 = conventional gas 3 = coal 4 = nonconventional oil
MAXR	= resource exhaustion logic variable MAXR = 0 resources available MAXR = 1 resources exhausted
NIG	= number of resource grades for each supply category (5)

NIS = number of supply categories (4)
 P = holding variable, world price of the supply category
 PIM = world price disaggregated by oil, gas, solids and by period M
 QISLM = cumulative production of resources of supply category IS in region L and period M
 R = holding variable for resources exhausted
 RIGISL = resources available at grade IG, for supply category IS in region L
 STISL = rate of technological progress for supply category IS in region L
 SLOPE = holding variable used to calculate QISLM
 TECH = holding variable for a technological change index for supply 1975 = 1
 V = holding variable for environmental costs of production
 VISL = environmental costs in the year 2050
 YLM = GNP in region L and period M.

The computer code is well annotated and for the most part self documenting. Fossil fuels are handled in subroutine SSSS. The first activities that the model engages in is to zero the total fuel counter.

```

593. C-----
594. C          LONG-RUN SUPPLY SCHEDULE FOR
595. C          IS=1= CONVENTIONAL OIL
596. C          2= CONVENTIONAL GAS
597. C          3= COAL
598. C          4= UNCONVENTIONAL OIL
599. C-----
700. C
701. C          +-----+
702. C          |          COMPUTE ESTIMATED CUMULATIVE PRODUCTION          |
703. C          +-----+
704. C
705. C          DO 80 L=1,NL
706. C
707. C          *****
708. C          *** ZERO TOTAL FUEL COUNTER ***
709. C
710. C          DO 100 L=1,NL
711. C          ESTL(1,L)=0.00
712. C          10 CONTINUE
713. C
  
```

The model next goes through fuel by fuel. For each supply category it begins by assuming that the resource base is not exhausted by setting the exhaustion logic variable (later it tests for resource exhaustion). The program then sets the fuels index to oil, gas, or solids.

```

C          +-----+
C          | ESTIMATE CUMULATIVE PRODUCTION TO DATE |
C          +-----+
C
C          DO 70 IS=1,NIS
C             MAXR=0
C
C          *****
C          ***   SET PRIMARY FUELS INDEX   ***
C          *****
C
C          I=IS
C          IF (IS.GT.NF) I=IS-NF

```

For the base year ESFIL is used to set output and the cumulative resource consumed from the base year is set to zero.

```

C          *****
C          ***   START BY ZEROING QISLM FOR (M.EQ.1) AND   ***
C          ***   SETTING OUTPUT TO ESFIL FOR 1975         ***
C          *****
C
C          IF (M.GT.1) GO TO 20
C
C          QISLM (IS,L,M)=0.00
C          E=ESFIL (IS,L)
C          GO TO 60

```

The model next identifies the world market price, P, computes the technology index, TECH, and the level of environmental costs V.

```

C          *****
C          ***   FOR (M.GT.1) COMPUTE CUMULATIVE PRODUC-   ***
C          ***   TION FROM THE DOMESTIC SUPPLY PRICE AND   ***
C          ***   THEN ESTIMATE ANNUAL PRODUCTION RATES    ***
C          *****
C          20      CONTINUE
C
C          +-----+
C          | COMPUTE RATE OF TECHNOLOGICAL |
C          | CHANGE AND ENVIRONMENTAL COST |
C          +-----+
C          P=PIM(I,M)
C          TLCH=(1.00+STISL (IS,L))*T
C          IF (N.LE.3) V=VISL (IS,L)*T/75.00
C          IF (M.GT.3) V=VISL (IS,L)

```

The model then searches over resource grades to find the grade at which production costs equal the world price; i.e., searches for the grade in which P is between $(CIGIS+V)/TECH$ (where $CIGIS$ is the minimum technical extraction cost in 1975 for grade IG) and $(CIGIS_++V)/TECH$ (where $CIGIS_+$ is the minimum technical extraction cost in 1975 for grade $IG+1$). When that grade is identified, the model branches to 40 CONTINUE. Note that at the same time, total resource extracted, R , is being computed. If $(CIGIS+V)/TECH$ never exceeds P for any grade, then it becomes profitable to consume the entire resource and the logic variable $MAXR$ is set to 1.

```

1755.      C      +-----+
1756.      C      | LOCATE THE MOST PROFITABLE. |
1757.      C      | RESOURCE GRADE             |
1758.      C      +-----+
1759.      C      NNIG=NIIG+1
1760.      C      R=0.00
1761.      C      DO 30 IG=1,NNIG
1762.      C      IF(IG.LE.NIIG) R=R+RIGISL(IG,IS,L)
1763.      C      C=CIGIS(IG,IS)
1764.      C      C=(C+V)/TECH
1765.      C      IF(C.GT.P) GO TO 40
1766.      JC      CONTINUE
1767.      C      MAXR=1

```

The model next computes cumulative production. If the price is below the minimum cost for grade 1, no production is allowed, while if $MAXR=1$, the entire resource is consumed.

```

1768.      C      +-----+
1769.      C      | COMPUTE CUMULATIVE PRODUCTION |
1770.      C      +-----+
1771.      C      40  CONTINUE
1772.      C      +-----+
1773.      C      | IF PRICES ARE TOO LOW ZERO |
1774.      C      | PRODUCTION. IF RESOURCE IS |
1775.      C      | EXHAUSTED SET QISLM TO MAX. |
1776.      C      +-----+
1777.      C      IF(IG.EQ.1) E=0.00
1778.      C      IF(IG.EQ.1) QISLM(IS,L,M)=QISLM(IS,L,M)+R
1779.      C      IF(IG.EQ.1) GO TO 50
1780.      C      IF(MAXR.EQ.1) QISLM(IS,L,M)=R
1781.      C      IF(MAXR.EQ.1) GO TO 50

```

If the resource is being exploited but not exhausted, the model then determines the actual amount of profitable cumulative production by summing the amounts of all resources of lower cost than the active grade (IG-1) plus the active grade itself

$$R = \frac{\text{IG-1}}{1} \text{RIGISL}$$

and then assuming that the amount of the active grade exploited is proportional to cost, i.e.

$$QISLM = R - \frac{\text{RIGISL}_{IG1} (C-P)}{\text{CIGIS}_{IG} - \text{CIGIS}_{IG1} / \text{TECH}}$$

```

'81.      C
'82.      C
'83.      C
'84.      C
'85.
'86.      IG1=IG-1
'87.      IG2=IG-2
'88.      SLOPE=RIGISL(IG1,IS,L)
'89.      SLOPE=SLOPE/((CIGIS(IG,IS)-CIGIS(IG1,IS))/TECH)
'90.      IF(IG.LE.NIG) R=R-RIGISL(IG,IS,L)
'91.      QISLM(IS,L,M)=R-SLOPE*(C-P)
          50      CONTINUE

```

The average annual production is simply the difference between cumulative production in the current and preceding periods, divided by the number of years per period. In addition, the average rate of production is assumed to be equal to the average of the first and final period's production

$$1/2(E_{t-1} + E_t) = (Q_t - Q_{t-1}) / TT$$

C
C
C
C

```

+-----+
| ESTIMATE ANNUAL PRODUCTION |
| RATE FROM CUMULATIVE PRODUCTION |
+-----+
IF (IS.LE.NF) E1=ESIL1M(I,L,MM1)
IF (IS.EQ.IUDIL) E1=ESIL2M(I,L,MM1)
E=2.D0*(QISLM(IS,L,M)-QISLM(IS,L,MM1))/TT-E1

```

The model then checks to make sure that calculated production is positive and if not assumes it to be zero and that no more of the resource was consumed.

C
C
C
C
C

```

+-----+
| MAKE SURE THAT OUTPUT IS POS- |
| ITIVE BUT WITHIN SHORT-TERM |
| CAPACITY LIMITS |
+-----+
IF (E.LE.0.D0) QISLM(IS,L,M)=QISLM(IS,L,MM1)
IF (E.LE.0.D0) E=0.D0

```

Calculations are not made to test whether or not production falls within expansion constraints. The minimum base level of production (used for example, if the resource was not exploited before period M) is BESIL. Otherwise base production is the previous year's production, E_1 , times the GNP growth factor (YLM_M/YLM_{M-1}). The maximum production constraint is scaled by the increase or decrease in price to the price elasticity power. If the constraint is binding then total resource consumption is limited.

```

B=BESIL(IS,L)
EHOLD=E1*YLM(L,M)/YLM(L,MM1)
IF (B.LT.EHOLD) B=EHOLD
P=PIM(I,H)/PIM(I,MM1)
B=B**RIL(I,L)
IF (B.LT.E) QISLM(IS,L,M)=QISLM(IS,L,MM1)+TT*(B+E1)/2.D0
IF (B.LT.E) E=B

```


The nonsupply module finishes by assigning output to the appropriate variables and zeroing the unconventional gas variable. Unconventional gas is now included with conventional gas.

```

C
C      +-----+
C      | ASSIGN OUTPUT TO SUPPLY VARIABLES |
C      +-----+
C      60      CONTINUE
C              IF (IS.LE.NF)  ESIL1M(I,L,M)=E
C              IF (IS.GT.NF)  ESIL2M(I,L,M)=E
C
C              ESIL(I,L) = ESIL(I,L) + E
C
C      70      CONTINUE
C              ESIL2M(IGAS,L,M)=0.00
C
C      80      CONTINUE

```

Nuclear power is handled very similarly to fossil fuels. Production is constrained by a resource base. The main problem faced in the nuclear power supply module is the determination of the nuclear power cost. As a consequence, this computation is made in subroutine PPPP. The code begins by estimating cumulative production for the period M based on either post-production using the following estimation procedure:

$$\begin{aligned}
 M = 1 & \quad QISLM = 0 \\
 M = 2 & \quad QISLM = 25 * ESUILM_{M-1} \\
 M \geq 3 & \quad QISLM = 1/2(ESUKM_{M-1} + ESUILM_{M-2}) * 25
 \end{aligned}$$

```

C-----
C      LONG-RUN SUPPLY SCHEDULE FOR
C      IS=5= NUCLEAR
C-----
C      +-----+
C      | ESTIMATE CUMULATIVE PRODUCTION TO DATE |
C      +-----+
C
C      IS=ISNUC
C      I=INUC
C      Q=0.00
C      IF(M.EQ.1) QISLM(IS,L,M)=0.00
C      IF(M.EQ.2) QISLM(IS,L,M)=TT*ESUILM(I,L,M-1)
C      IF(M.GE.3) QISLM(IS,L,M-1)=ESUILM(I,L,M-2)+ESUILM(I,L,M-1)
C      IF(M.GE.3) QISLM(IS,L,M-1)=QISLM(IS,L,M-1)*TT/2.00
C      IF(M.GE.3) QISLM(IS,L,M)=2.00*QISLM(IS,L,M-1)-QISLM(IS,L,
C      Q=Q+QISLM(IS,L,M)
C      30 CONTINUE

```

With an estimate of the resource exhaustion by period M, the model then goes on to find the cost at which that amount of resource would be consumed and sets that equal to the fuel cost of nuclear power, PILM for nuclear. The first step in this process is to identify which of the five resource grades is active.

```

1521.      C      +-----+
1522.      C      | USE CUMULATIVE PRODUCTION TO COMPUTE NUCLEAR PRICE |
1523.      C      +-----+
1524.      C
1525.      C      *****
1526.      C      *** FIND RESOURCE GRADE CURRENTLY ***
1527.      C      *** BEING PRODUCED ***
1528.      C      *****
1529.      C
1530.      C      R=0.00
1531.      C      DO 50 IG=1,NIG
1532.      C      W=0.00
1533.      C      DO 40 L=1,NL
1534.      C      W=W+RIGISL(IG,IS,L)
1535.      C      R=R+RIGISL(IG,IS,L)
1536.      C      40 CONTINUE
1537.      C      IF(Q.LE.R) GO TO 70
1538.      C      50 CONTINUE

```

If the resource is exhausted, nuclear fuel costs are set at an arbitrarily high level to keep utilities from installing new capacity, which aids the PPPP subroutine.

```

1539.      C
1540.      C      *****
1541.      C      *** IF RESOURCE IS EXHAUSTED, SET ***
1542.      C      *** CIL=100 ***
1543.      C      *****
1544.      C
1545.      C      DO 60 L=1,NL
1546.      C      CIL(IS,L)=100.00
1547.      C      PILM(4,L,M)=CIL(IS,L)
1548.      C      60 CONTINUE
1549.      C      RETURN

```

If the resource is not exhausted, then the technical extraction costs, C, are calculated, as are the environmental costs, V, and the technology index TECH. These three elements are then combined to compute the nuclear fuel cost, PILM.

```

1551.      C      ****
1552.      C      ***  CALCULATE EXTRACTION COSTS  ***
1553.      C      ***  EXCLUDING TECHNOLOGICAL CHANGE  ***
1554.      C      ***  AND ENVIRONMENTAL COSTS  ***
1555.      C      ****
1556.      C
1557.      C      70  CONTINUE
1558.      C
1559.      C      IG1=IG+1
1560.      C      W=(P-Q)/W
1561.      C      C=4*CIGIS(IG,IS)+(1.00-W)*CIGIS(IG1,IS)
1562.      C
1563.      C      ****
1564.      C      ***  CALCULATE TECHNOLOGICAL CHANGE  ***
1565.      C      ***  AND ENVIRONMENTAL COSTS  ***
1566.      C      ****
1567.      C
1568.      C      DO 80 L=1,NL
1569.      C      TECH=(1.00+STISL(IS,L))*T
1570.      C
1571.      C      IF(M.LE.3) V=VISL(IS,L)*T/75.00
1572.      C      IF(M.GT.3) V=VISL(IS,L)
1573.      C
1574.      C      ****
1575.      C      ***  COMBINE EXTRACTION COSTS,  ***
1576.      C      ***  ENVIRONMENTAL COSTS, AND TECH-  ***
1577.      C      ***  NOLOGICAL CHANGE TO CALCULATE  ***
1578.      C      ***  NUCLEAR COST  ***
1579.      C      CIL(IS,L)=(C+V)/TECH
1580.      C      FILM(4,L,M)=CIL(IS,L)
1581.      C      80  CONTINUE
1582.      C
1583.      C      RETURN
1584.      C
1585.      C      END

```

Reading in New Data Elements. The data elements are read in subroutine READ. The code used to perform that task is listed below followed by the data base of median input values.

COMPUTER CODE TO READ SUPPLY FOR MODEL VERSION A.84

```

79. C
80. C -----
81. C
82. C
83. C      READ RIGISL--RESOURCE BASE AMOUNTS
84. C
85. C      DO 700 KK=1,4
86. C        READ (IUNIT,1100) A
87. C        IF (NOPT(2).EQ. 1) GO TO 700
88. C        WRITE(JUNIT,2100) A
89. C      700 CONTINUE
90. C
91. C      DO 710 IG=1,NIG
92. C
93. C        DO 712 KK=1,4
94. C          READ (IUNIT,1100) A
95. C          IF (NOPT(2).EQ. 1) GO TO 712
96. C          WRITE(JUNIT,2100) A
97. C        712 CONTINUE
98. C
99. C        DO 714 L=1,NL
100. C          READ (IUNIT,1030) (RIGISL(IG,IS,L),IS=1,NNIS),NOTES
101. C          IF (NOPT(2).EQ. 1) GO TO 714
102. C          WRITE(JUNIT,2033) (RIGISL(IG,IS,L),IS=1,NNIS),NOTES
103. C        714 CONTINUE
104. C      710 CONTINUE
105. C
106. C
107. C
108. C
109. C      READ CIGIS--EXTRACTION COST AMOUNTS
110. C
111. C      DO 720 KK=1,8
112. C        READ (IUNIT,1100) A
113. C        IF (NOPT(2).EQ. 1) GO TO 720
114. C        WRITE(JUNIT,2100) A
115. C      720 CONTINUE
116. C
117. C      NNIG=NNIG+1
118. C      DO 722 IG=1,NNIG
119. C        READ (IUNIT,1030) (CIGIS(IG,IS),IS=1,NNIS),NOTES
120. C        IF (NOPT(2).EQ. 1) GO TO 722
121. C        WRITE(JUNIT,2034) (CIGIS(IG,IS),IS=1,NNIS),NOTES
122. C      722 CONTINUE
123. C
124. C
125. C
126. C
127. C      READ--VISL ENVIRONMENTAL COST AMOUNTS
128. C
129. C      DO 730 KK=1,6
130. C        READ (IUNIT,1100) A
131. C        IF (NOPT(2).EQ. 1) GO TO 730
132. C        WRITE(JUNIT,2100) A
133. C      730 CONTINUE
134. C
135. C      DO 734 L=1,NL
136. C        READ (IUNIT,1030) (VISL(IS,L),IS=1,NNIS),NOTES
137. C        IF (NOPT(2).EQ. 1) GO TO 734
138. C        WRITE(JUNIT,2034) (VISL(IS,L),IS=1,NNIS),NOTES
139. C      734 CONTINUE
140. C      750 CONTINUE

```

```

339. C
340. C
341. C
342. C
343. C
344. C
345. C
346. C
347. C
348. C
349. C
350. C
351. C
352. C
353. C
354. C
355. C
356. C
357. C
358. C
359. C
360. C
361. C
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379. C
380. C
381. C
382. C
383. C
384. C
385. C
386. C
387. C
388. C
389. C
390. C
391. C
392. C
393. C
394. C
395. C
396. C
397. C
398. C
399. C
1000. C
1001. C

      READ RIL--PRICE ELASTICITY OF SUPPLY FOR
      FOSSIL FUELS, EVALUATED AT DILSET

DO 752 KK=1,6
  READ (IUNIT,1100) A
  IF (NOPT(2).EQ. 1) A GO TO 752
  WRITE(JUNIT,2100) A
752 CONTINUE

DO 754 L=1,NL
  READ (IUNIT,1020) (RIL(IS,L),IS=1,NIS),NOTES
  IF (NOPT(2).EQ. 1) GO TO 754
  WRITE(JUNIT,2020) (RIL(IS,L),IS=1,NIS),NOTES
754 CONTINUE

      READ STISL--RATE OF TECHNOLOGICAL CHANGE
      BY SUPPLY MODE AND REGION

DO 758 KK=1,7
  READ (IUNIT,1100) A
  IF (NOPT(2).EQ. 1) A GO TO 758
  WRITE(JUNIT,2100) A
758 CONTINUE

DO 760 L=1,NL
  READ (IUNIT,1030) (STISL(IS,L),IS=1,NNIS),NOTES
  IF (NOPT(2).EQ. 1) GO TO 760
  WRITE(JUNIT,2030) (STISL(IS,L),IS=1,NNIS),NOTES
760 CONTINUE

      READ BESIL--MINIMUM LEVEL OF SHORT TERM
      SUPPLY AND REGION

DO 768 KK=1,7
  READ (IUNIT,1100) A
  IF (NOPT(2).EQ. 1) A GO TO 768
  WRITE(JUNIT,2100) A
768 CONTINUE

DO 770 L=1,NL
  READ (IUNIT,1030) (BESIL(IS,L),IS=1,NNIS),NOTES
  IF (NOPT(2).EQ. 1) GO TO 770
  WRITE(JUNIT,2034) (BESIL(IS,L),IS=1,NNIS),NOTES
770 CONTINUE

      READ ESFIL--INITIAL ENERGY SUPPLY ESTIMATES

DO 772 KK=1,10
  READ (IUNIT,1100) A
  IF (NOPT(2).EQ. 1) A GO TO 772
  WRITE(JUNIT,2100) A
772 CONTINUE

DO 778 L=1,NL
  READ (IUNIT,1030) (ESFIL(IS,L),IS=1,NNIS),NOTES
  IF (NOPT(2).EQ. 1) GO TO 778
  WRITE(JUNIT,2030) (ESFIL(IS,L),IS=1,NNIS),NOTES
778 CONTINUE

```

SAMPLE SUPPLY COEFFICIENT DATA FILE FOR MODEL VERSION A.84

PIGISEL--RESOURCES BY GRADE AND REGION.
(UNITS=EXAJOULES)

GRADE: IG=1

	CONV OIL	CONV GAS	COAL	UNCON OIL	NUCLEAR	REGION
6502.						1=USA
6503.						2=WEUR+CAN
6504.						3=OECD PAC
6505.						4=EUSSR
6506.						5=ACENP
6507.						6=MIDEAST
6508.						7=AFRICA
6509.						8=L AMER
6510.	77.	570.	7954.	4591.	109.	9=SEE ASIA
6511.	100.	434.	2439.	2142.	200.	
6512.	3.	70.	1891.	1564.	97.	
6513.	190.	1324.	13536.	4294.	267.	
6514.	62.	173.	4054.	2147.	128.	
6515.	400.	1054.	2.	537.	2.	
6516.	180.	346.	607.	6411.	442.	
6517.	159.	365.	121.	3205.	1010.	
6518.	29.	100.	365.	1610.	21.	

GRADE: IG=2

	CONV OIL	CONV GAS	COAL	UNCON OIL	NUCLEAR	REGION
6522.	221.	227.	9763.	9170.	534.	1=USA
6523.	290.	179.	3015.	4138.	1058.	2=WEUR+CAN
6524.	9.	20.	2313.	3057.	519.	3=OECD PAC
6525.	550.	547.	16592.	9397.	1426.	4=EUSSR
6526.	151.	73.	4970.	4147.	682.	5=ACENP
6527.	1000.	435.	2.	1049.	12.	6=MIDEAST
6528.	436.	142.	745.	12532.	2356.	7=AFRICA
6529.	334.	151.	148.	8266.	5388.	8=L AMER
6530.	70.	56.	447.	3148.	113.	9=SEE ASIA

GRADE: IG=3

	CONV OIL	CONV GAS	COAL	UNCON OIL	NUCLEAR	REGION
6535.	441.	510.	13874.	98173.	100000.	1=USA
6536.	577.	330.	4284.	40266.	100000.	2=WEUR+CAN
6537.	17.	53.	3234.	29391.	100000.	3=OECD PAC
6538.	1095.	1007.	23578.	80708.	100000.	4=EUSSR
6539.	267.	135.	7062.	40354.	100000.	5=ACENP
6540.	890.	802.	3.	10088.	100000.	6=MIDEAST
6541.	771.	263.	1058.	120503.	100000.	7=AFRICA
6542.	679.	279.	211.	60252.	100000.	8=L AMER
6543.	123.	121.	635.	30266.	100000.	9=SEE ASIA

GRADE: IG=4

	CONV OIL	CONV GAS	COAL	UNCON OIL	NUCLEAR	REGION
6548.	373.	582.	19012.	254516.	100000.	1=USA
6549.	488.	377.	5871.	120797.	100000.	2=WEUR+CAN
6550.	14.	61.	4515.	33173.	100000.	3=OECD PAC
6551.	925.	1150.	32311.	242123.	100000.	4=EUSSR
6552.	204.	155.	9678.	121062.	100000.	5=ACENP
6553.	3650.	916.	4.	30253.	100000.	6=MIDEAST
6554.	591.	301.	1450.	361510.	100000.	7=AFRICA
6555.	520.	318.	289.	180755.	100000.	8=L AMER
6556.	94.	139.	871.	90797.	100000.	9=SEE ASIA

GRADE: IG=5

	CONV OIL	CONV GAS	COAL	UNCON OIL	NUCLEAR	REGION
6561.	292.	0.	19012.	0.	0.	1=USA
6562.	382.	0.	5871.	0.	0.	2=WEUR+CAN
6563.	11.	0.	4515.	0.	0.	3=OECD PAC
6564.	725.	0.	32311.	0.	0.	4=EUSSR
6565.	154.	0.	9678.	0.	0.	5=ACENP
6566.	1460.	0.	4.	0.	0.	6=MIDEAST
6567.	1444.	0.	1450.	0.	0.	7=AFRICA
6568.	391.	0.	289.	0.	0.	8=L AMER
6569.	371.	0.	871.	0.	0.	9=SEE ASIA

6531.
6532.
6533.
6534.
6535.
6536.

BESIL--MINIMUM LEVEL OF SHORT-TERM SUPPLY BY TYPE
AND REGION

	CONV OIL	CONV GAS	COAL	UNCON OIL	NUCLEAR	REGION
6537.	0.03	0.03	0.03	0.03	0.03	1=USA
6538.	0.03	0.03	0.03	0.03	0.03	2=WEUR+CAN
6539.	0.03	0.03	0.03	0.03	0.03	3=OECD PAC
6540.	0.03	0.03	0.03	0.03	0.03	4=EUSSR
6541.	0.03	0.03	0.03	0.03	0.03	5=ACENP
6542.	0.03	0.03	0.03	0.03	0.03	6=MIDEAST
6543.	0.03	0.03	0.03	0.03	0.03	7=AFRICA
6544.	0.03	0.03	0.03	0.03	0.03	8=L AMER
6545.	0.03	0.03	0.03	0.03	0.03	9=S&E ASIA
6546.	0.03	0.03	0.03	0.03	0.03	
6547.						
6548.						
6549.						

6550.
6551.
6552.
6553.
6554.
6555.

ESFIL--INITIAL ESTIMATE OF ENERGY SUPPLY
BY FUEL, REGION, AND PERIOD
(UNITS=EXAJOULES/YR)

YEAR=1975

	CONV OIL	CONV GAS	COAL	UNCON OIL	NUCLEAR	REGION
6556.	20.41	20.73	17.18	0.0	0.52	1=USA
6557.	4.77	8.98	9.50	0.0	0.58	2=WEUR+CAN
6558.	0.95	0.31	2.67	0.0	0.09	3=OECD PAC
6559.	22.77	11.91	15.77	0.0	0.07	4=EUSSR
6560.	33.23	0.14	15.01	0.0	0.00	5=ACENP
6561.	42.35	1.21	0.03	0.0	0.00	6=MIDEAST
6562.	10.59	0.39	0.18	0.0	0.00	7=AFRICA
6563.	3.92	1.55	10.39	0.0	0.01	8=L AMER
6564.	4.79	0.75	4.68	0.0	0.01	9=S&E ASIA
6565.						

COMPUTATIONAL CHANGES

Major computational changes were introduced into the equilibrium mechanism of the model. First the role of transportation costs was changed, and second a new procedure was added to the equilibrium search process.

Transport Costs

The original model version B.82 employed a complicated procedure which attempted to identify unambiguously regions which imported and exported oil, gas and solids. There were two problems with this procedure. First, the model was rarely able to make such unambiguous distinctions. In most cases transport costs were sufficiently great that if a region was assumed to be an importer, that the addition of transport cost raised the price to consumers to the point that the region's consumption fell below production and the region became a net exporter. On the other hand, the removal of the tariff often lowered the price to consumers sufficiently that consumption exceeded production and the region became a net importer. The model would thus become caught in an endless cycle unless some intervention was made. In model Version B.82 that intervention took the form setting transport costs to one-half their usual values in all region-fuel cases where indeterminance was occurring. Most regions were characterized by this problem for all three fuels (though less so for oil, where transport costs were smaller relative to the fuel costs). This equilibrium search procedure was lengthy and for the most part resulted in an arbitrary solution in the end.

The second problem was that despite or perhaps in some cases because of this procedure, the model eventually encountered unusual price/transport cost combinations which sometimes took the model into regions from which its Newtonian search algorithm was unable to find an equilibrium solution and would eventually crash. The solution found to this problem was to go directly to an arbitrary assignment of transport costs. All consumers in all regions for all fuels were assumed to pay one-half of the transport costs after the initial period. This resulted in the elimination of a whole matrix of logic variables such as NIXIL and NHXIL which controlled importer-exporter status.

The more complicated code of model B.82 is simplified from

```

C
C      --COMPUTE REGIONAL FOSSIL FUEL PRICES
C
      DO 10 I=1,NF
        PILM(I,L,M)=PI(I) * TXILM(I,L,M)
        IF (NXIL(I,L) .LT. 0) PILM(I,L,M)=(PI(I)+TRI(I))*TXILM(I,L,M)
10    CONTINUE

C
C      -----
C      --      IF THE MODEL HAS RECYCLED, SET TRANSPORT COSTS      --
C      --      TO 1/2 NORMAL VALUE IN INCONSISTENT REGION-FUEL CASES  --
C      -----
      IF (NCATCH .NE. 0) GO TO 17
      DO 14 I=1,NF
        NX=NXIL(I,L)*NHXIL(I,L)
        IF (NX .LT. 0.00) PILM(I,L,M)=(PI(I)+TRI(I)/2.00)*TXILM(I,L,M)
14    CONTINUE
17    CONTINUE

```

to

```

1469. C *****
1470. C
1471. C      +-----+
1472. C      I      SET PRIMARY ENERGY PRICES      I
1473. C      +-----+
1474. C
1475. C      DO 20 L=1,NL
1476. C      +-----+
1477. C      I      COMPUTE REGIONAL FOSSIL FUEL PRICES      I
1478. C      +-----+
1479. C      DO 10 I=1,NF
1480. C      PIRM(I,L,M)=(PIR(I,M)+TRI(I))*TXILM(I,L,M)
1481. C      IF (N.NE.1) PIRM(I,L,M)=(PIR(I,M)+TRI(I)/2.D0)*TXILM(I
1482. C      10 CONTINUE
1483. C      20 CONTINUE
1484. C
1485. C      *****
1486. C      *** IF NOT THE FIRST TIME THROUGH ***
1487. C      *** NUCLEAR, SOLAR, AND HYDRO COSTS ***
1488. C      *** WERE COMPUTED. ROUTINE RETURNS ***
1489. C      *****
1490. C      IF(NAGN.NE.0) RETURN
1491. C *****

```

Note the departure of the logic variable NCATCH which signified when the model's equilibrium search mechanism had become locked in an indeterminant cycle and that an arbitrary solution was necessary. The arbitrary solution of the line above 24 CONTINUE in model B.82 becomes the basic price determination equation.

In model version A.84 the costs of nuclear, solar and hydro are calculated only once per period (on the first pass when NAGN=0) as they are independent of the world prices of oil, gas and solids.

These changes also streamline the subroutine XXXX. In model version B.82 XXXX contains 72 lines of code:

SUBROUTINE XXXX IN MODEL VERSION B.82

INITIALIZE THE MARKET CONVERGENCE COUNTER, NFAIL, AT ZERO

NFAIL=0

DO 10 I=1,NMKT
 EDIMKT(I)=0.00
 ESIMKT(I)=0.00

 -- SUM UP ENERGY DEMAND AND SUPPLY BY REGION --

DO 20 L=1,NL
 EDIMKT(I)=EDIMKT(I)+EDRIL(I,L)
 ESIMKT(I)=ESIMKT(I)+ESRILM(I,L,M)

20 CONTINUE

 -- TEST TO SEE IF EXCESS DEMAND IS WITHIN LIMITS --

XI(I)=DLOG(EDIMKT(I))-DLOG(ESIMKT(I))
 IF ((XI(I) .GT. TEST) .OR. (XI(I) .LT. -TEST)) NFAIL=1

10 CONTINUE

-----+
 IF EXCESS DEMAND IN ANY SECTOR IS OUTSIDE OF THE LIMITS, THEN
 CALL REVISE TO GENERATE A MORE EQUILIBRICUS SET OF PRICES.
 OTHERWISE CONTINUE ON TO CHECK FOR CONSISTENCY OF THE EXPORT/
 IMPORT SPECIFIERS, NXIL, WITH ACTUAL EXPORT/IMPORT BEHAVIOR.
 -----+

IF (NFAIL .NE. 1) GO TO 40

30 CALL REVISE

-- OUTPUT OPTION CONTROL

IF(NOPT(3)-1) 31,32,31

31 CONTINUE

-----+
 | INTERMEDIATE OUTPUT SECTION |
 -----+

WRITE(6,1000) M, NAGN
 WRITE(6,1100) (I,ESIMKT(I),I=1,NMKT)
 WRITE(6,1200) (I,EDIMKT(I),I=1,NMKT)
 WRITE(6,1250) PI

1000 FORMAT(1H0,'PERIOD ',I1,4X,'ITERATION ',I2)
 1100 FORMAT(1H0,3('ESIMKT(',I1,')=',F10.4,2X))
 1200 FORMAT(1X,3('EDIMKT(',I1,')=',F10.4,2X))
 1250 FORMAT(1H0,'OIL PRICE=',F10.4,2X,'GAS PRICE=',F10.4,2X,
 & 'COAL PRICE=',F9.4)

32 CONTINUE

```

C
C
C      +-----+
C      |   END INTERMEDIATE OUTPUT   |
C      +-----+
C
C      RETURN
C
C
C 40 CONTINUE
C
C      +-----+
C      |   CHECK TO SEE IF THE LATEST CONVERGED STATE   |
C      |   WAS A FINAL RUN OF A RECYCLED CASE. IF IT   |
C      |   WAS THEN DO NOT CHECK FOR CONSISTENCY, AND   |
C      |   SEND FINAL RESULTS TO POST PROCESSING AND   |
C      |   THE PRINT SUBROUTINES.                     |
C      +-----+
C      IF (NCATCH .EQ. 0)   NAJUST=0
C      IF (NCATCH .EQ. 0)   GO TO 100
C
C
C      +-----+
C      |   CHECK FOR CONSISTENCY BETWEEN EXPORT/IMPORT BEHAVIOR AND THE   |
C      |   EXPORT/IMPORT SPECIFIER--NXIL.                               |
C      +-----+
C
C      NAJUST=0
C      NCATCH=0
C      MXTRIP=MXTRIP+1
C      DO 60 I=1,NMKT
C          DO 55 L=1,NL
C              NHOLD=NXIL(I,L)
C              X=NXIL(I,L)
C              X=X*(ESRILM(I,L,M)-EDRIL(I,L))
C              IF (X-0.00) 45,50,50
C 45          NXIL(I,L)=-NXIL(I,L)
C              NAJUST=NAJUST+1
C 50          CONTINUE
C              NX=NXIL(I,L)*NHXIL(I,L)
C              IF (NX .LT. 0)   NCATCH=1
C              NHXIL(I,L)=NHOLD
C 55          CONTINUE
C 60          CONTINUE
C
C      -- OUTPUT OPTION CONTROL
C
C      IF(NOPT(3)-1) 65,80,65
C
C 65 CONTINUE

```

```

C
C
C      +-----+
C      | INTERMEDIATE OUTPUT SECTION |
C      +-----+
C
C      WRITE(6,1300) NAGN
C      WRITE(6,1100) (I,ESIMKT(I),I=1,NMKT)
C      WRITE(6,1200) (I,EDIMKT(I),I=1,NMKT)
C      WRITE(6,1250) PI
C      IF(NAJUST-1) 80,70,70
70  WRITE(6,1400) NAJUST
C      DO 75 L=1,NL
C          WRITE(6,1500) (I,L,NXIL(I,L),I=1,NMKT)
75  CONTINUE
1300 FORMAT(1H0,'FINAL XXXX OUTPUT REACHED AFTER',I3,' ITERATIONS')
1400 FORMAT(1H0,I2,' EXPORTER/IMPORTER CHANGES HAVE OCCURRED')
1500 FORMAT(1X,3('NXIL(',I1,',',I1,',')=' ',I2,5X))
C
C 80  CONTINUE
C
C      +-----+
C      | END INTERMEDIATE OUTPUT |
C      +-----+
C
C      IF (NCATCH .EQ. 1) GO TO 100
C
C -- OUTPUT OPTION CONTROL
C
C      IF(NOPT(3)-1) 90,100,90
C
C 90 CONTINUE
C
C      WRITE(6,1700)
1700 FORMAT(1H0,'EXPORT/IMPORT MATRIX HAS RECYCLED TO PREVIOUS STATE --
      & TRANSPORT COST SET TO 1/2 NORMAL VALUE IN INCONSISTENT REGIONS.')
C      RETURN
C
C 100 CONTINUE
C      NAGN=NAGN+1
C
C      RETURN
C      END

```

Model Version A.84 is essentially the first 28 lines of model Version B.82
with all following material rendered unnecessary.

THE PREVIOUS MODELING SOLUTIONS ARE:

SUBROUTINE XXXX MODEL VERSION A.84

```

2487. C
2488. C INITIALIZE THE MARKET CONVERGENCE COUNTER, NFAIL, AT ZERO
2489. C
2490. C NFAIL=0
2491. C
2492. C
2493. C DO 10 I=1,NMKT
2494. C EDIMKT(I)=1.00
2495. C ESIMKT(I)=1.00
2496. C
2497. C -----
2498. C -- SUM UP ENERGY DEMAND AND SUPPLY BY REGION --
2499. C -----
2500. C DO 20 L=1,NL
2501. C EDIMKT(I)=EDIMKT(I)+EDRIL(I,L)
2502. C ESIMKT(I)=ESIMKT(I)+ESRILM(I,L,M)
2503. C 20 CONTINUE
2504. C -----
2505. C -- TEST TO SEE IF EXCESS DEMAND IS WITHIN LIMITS --
2506. C -----
2507. C XI(I)=DLOG(EDIMKT(I))-DLOG(ESIMKT(I))
2508. C IF ((XI(I) .GT. TEST) .OR. (XI(I) .LT. -TEST)) NFAIL=1
2509. C
2510. C 10 CONTINUE
2511. C +-----+
2512. C | IF EXCESS DEMAND IN ANY SECTOR IS OUTSIDE OF THE LIMITS, I
2513. C | CALL REVISE TO GENERATE A MORE EQUILIBRIOUS SET OF PRICES.
2514. C +-----+
2515. C IF(NFAIL.EQ.0) NAGN=NAGN+1
2516. C IF(NFAIL.EQ.1) GO TO 30
2517. C
2518. C CALL REVISE
2519. C 30 CONTINUE
2520. C
2521. C -- JUTPUT OPTION CONTROL
2522. C
2523. C IF(NOPT(3)-1) 31,32,31
2524. C
2525. C 31 CONTINUE
2526. C
2527. C +-----+
2528. C | INTERMEDIATE OUTPUT SECTION |
2529. C +-----+
2530. C
2531. C WRITE(6,1000) M, NAGN
2532. C WRITE(6,1100) (I,ESIMKT(I),I=1,NMKT)
2533. C WRITE(6,1200) (I,EDIMKT(I),I=1,NMKT)
2534. C WRITE(6,1250) (PIN(I,M),I=1,NMKT)
2535. C 1000 FORMAT(1H0,'PERIOD ',I1,4X,'ITERATION ',I2)
2536. C 1100 FORMAT(1H0,3('ESIMKT(',I1,')=',F10.4,2X))
2537. C 1200 FORMAT(1X,3('EDIMKT(',I1,')=',F10.4,2X))
2538. C 1250 FORMAT(1H0,'OIL PRICE=',F10.4,2X,'GAS PRICE=',F10.4,2X,
2539. C & 'COAL PRICE=',F9.4)
2540. C
2541. C 32 CONTINUE
2542. C
2543. C RETURN
2544. C END

```

The model's machinery for checking whether or not initial assumptions about region-fuel import-export status were consistent with model results and to check for indeterminant cycles in the models equilibrium search procedure has been removed.

Not only did the elimination of that mechanism eliminate 46 lines of code, but it also reduced run time for a model solution by 80 percent.

Search Procedure

In 5 to 10 percent of the cases encountered in the Monte Carlo analysis, the model's modified Newtonian search mechanism was unable to find a set of energy prices to clear world markets. These conditions would lead to the ultimate failure of the case to converge. To deal with such cases, a new, non-Newtonian procedure was sought. The approach selected was a "brute force" search grid procedure.

The new subroutine was called PUNT. As the name implies, the subroutine was called as a last resort when the usual Newtonian procedure was failing. The subroutine operates on market prices. It begins with the last set of prices considered by the Newtonian procedure. It then builds an N-dimensional box around that price vector which is then systematically marked off into a grid. The intersections of the grid are price vectors which the model sequentially explores.

The figure below illustrates how the procedure works when there are only two prices, PA and PB. The subroutine starts with the point (PA, PB). A minimum searchable price for each is obtained by dividing the initial price (PA or PB) by a scale factor, AREA, so that

$$PA_{\min} = PA/AREA$$

$$PB_{\min} = PB/AREA$$

Maximum prices are obtained such that

$$PA_{\max} - PA = PA - PA_{\min}$$

$$PB_{\max} - PB = PB - PB_{\min}.$$

That is $PA_{\min}$ and $PA_{\max}$ are equidistant from PA .

The variable NGRID determines how many prices are considered for each market. For example in the Figure B-2 below, NGRID=4. There are four possible PA's and four possible PB's. Thus there are 16 possible combinations of PA and PB,

(PA_1, PB_1)	(PA_1, PB_2)	(PA_1, PB_3)	(PA_1, PB_4)
(PA_2, PB_1)	(PA_2, PB_2)	(PA_2, PB_3)	(PA_2, PB_4)
(PA_3, PB_1)	(PA_3, PB_2)	(PA_3, PB_3)	(PA_3, PB_4)
(PA_4, PB_1)	(PA_4, PB_2)	(PA_4, PB_3)	(PA_4, PB_4)

In general there are $NGRID^{NMKT}$ possible combinations.

The subroutine systematically explores each price combination and runs the model to see what market supply and demand are.

Figure B-2. Sample Search Grid Construction for Subroutine PUNT

To facilitate the use of PUNT, subroutine REVISE has been changed in four places in version A.84 (as circled). First, a test index NPUNT is initialized. NPUNT determines whether or not PUNT is called. Here it is set to 5. This means that if after the model has tried and failed to find an equilibrium using the Newtonian (derivative) method (see Software Description) and has tried and failed to improve its position by shortening the price change vector five times without success, it will call PUNT.

If both NAGN exceeds zero and NDOWN is less than or equal to NPUNT, the subroutine goes on to calculate a new value for X, the market convergence metric, and compares it to OLDX. If X is smaller than OLDX, then the program branches to 5 CONTINUE where it goes on to calculate a new equilibrium price estimate. If X is larger than OLDX then the model checks to see whether this situation has occurred NPUNT consecutive times. The NDOWN counter is then increased by one. And if PUNT was called the subroutine returns with a new set of prices from PUNT.

[illegible]

SUBROUTINE REVISE IN MODEL VERSION A.84

```

2584.5 C *****
2585.5 C *** SLT NPUNT TEST VARIABLE USED TO *****
2585.5 C *** INITIATE THE AREA SEARCH ROUTINE *****
2586.5 C *****
2586.5 C
2587.5 C NPUNT=5
2587.5 C *****
2588.5 C *** IF THIS IS THE FIRST TIME THROUGH THE ***
2588.5 C *** CONVERGENCE PROCESS THEN SKIP THIS SECTION. ***
2589.5 C *****
2589.5 C
2590.5 C IF(NAGN.EQ.0) GO TO 5
2590.5 C IF(NDOWN.GT.NPUNT) GO TO 5
2591.5 C
2591.5 C
2592.5 C
2592.5 C
2593.5 C
2593.5 C
2594.5 C
2594.5 C
2595.5 C
2595.5 C
2596.5 C
2596.5 C
2596.5 C
2597.5 C
2597.5 C
2597.5 C
2598.5 C
2598.5 C
2598.5 C
2599.5 C
2599.5 C
2599.5 C
2600.5 C
2600.5 C
2600.5 C
2601.5 C
2601.5 C
2601.5 C
2602.5 C
2602.5 C
2602.5 C
2603.5 C
2603.5 C
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2606.5 C
2607.5 C
2607.5 C
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2608.5 C
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2613.5 C
2614.5 C
2614.5 C
2614.5 C
2615.5 C
2615.5 C
2615.5 C
2616.5 C

```

 *** SLT NPUNT TEST VARIABLE USED TO *****
 *** INITIATE THE AREA SEARCH ROUTINE *****

 NPUNT=5

 *** IF THIS IS THE FIRST TIME THROUGH THE ***
 *** CONVERGENCE PROCESS THEN SKIP THIS SECTION. ***

 IF(NAGN.EQ.0) GO TO 5
 IF(NDOWN.GT.NPUNT) GO TO 5

 CHECK TO SEE IF CONVERGENCE IS ACTUALLY OCCURRING:
 A POSITION IS CONSIDERED IMPROVED
 IF THE TOTAL VARIANCE OF THE POSITION
 HAS DECREASED.

 INITIALIZE "X", THE CURRENT
 VARIANCE FROM EQUILIBRIUM VARIABLE, AND "OLDX" THE PREVIOUS
 ITERATION'S VARIANCE REGISTER TO 0.0
 X=0.0
 OLDX=0.0
 DO 2 I=1,NMKT
 X=X+XI(I)**2
 OLDX=OLDX+OLDXI(I)**2
 2 CONTINUE
 IF (X .LT. OLDX) GO TO 5
 IF X IS NOT LESS THAN OLDX THEN DEMAND AND SUPPLY ARE DIVERGING
 IF DEMAND AND SUPPLY ARE ACTUALLY DIVERGING, HALVE THE PRICE CH
 ON THE NPUNT-TH CONSECUTIVE PASS WITH DIVERGING
 EQUILIBRIUM, CALL PUNT
 IF(NDOWN.EQ.NPUNT) CALL PUNT
 NDOWN=NDOWN+1
 IF(NDOWN.GT.NPUNT) RETURN
 3 DO 4 I=1,NMKT
 DP(I)=.25D0*DP(I)
 4 CONTINUE
 SKIP DOWN TO NEW PRICE COMPUTATION
 GO TO 70

 *** COMPUTE SUPPLY AND DEMAND ELASTICITIES ***

 5 CONTINUE
 NDOWN=0
 CALL ELAS
 COMPUTE THE PRICE ELASTICITY DEMAND - SUPPLY DIFFERENCE MATRIX
 DO 20 I=1,NMKT
 DO 10 J=1,NMKT
 W(I,J)=UIJ(I,J)-VIJ(I,J)
 10 CONTINUE
 20 CONTINUE

```

2616.5 C
2617.5 C SOLVE FOR REQUIRED PRICE CHANGES
2618.5 C
2619.5 C FIRST, COMPUTE 'W' INVERSE:
2620.5 C
2621.5 C CALL MINV(W,NMKT,DETERM,VEC1,VEC2)
2622.5 C (NOTE: SUBROUTINE MINV ZEROES OUT DETERM, VEC1, AND VEC2)
2623.5 C
2624.5 C -----
2625.5 C -- INDICATE THAT MINV HAS BEEN CALLED --
2626.5 C -----
2627.5 C NTIMES=NTIMES+1
2628.5 C
2629.5 C -- OUTPUT OPTION CONTROL
2630.5 C
2631.5 C IF(NOPT(3)-1) 110,210,110
2632.5 C
2633.5 C 110 CONTINUE
2634.5 C
2635.5 C +-----+
2636.5 C | INTERMEDIATE OUTPUT |
2637.5 C +-----+
2638.5 C WRITE(6,1000) NTIMES
2639.5 C 1000 FORMAT(1X,'MINV HAS BEEN SUCCESSFULLY CALLED. NTIMES=',I2)
2640.5 C
2641.5 C |END INTERMEDIATE OUTPUT|
2642.5 C +-----+
2643.5 C 210 CONTINUE
2644.5 C
2645.5 C -----
2646.5 C | SOLVE FOR DP(I) |
2647.5 C | AND CHECK FOR NEGATIVE ADJUSTED PRICES |
2648.5 C -----
2649.5 C
2650.5 C DO 40 I=1,NMKT
2651.5 C DP(I)=0.0
2652.5 C DO 30 J=1,NMKT
2653.5 C TEMP=-W(I,J)*XI(J)
2654.5 C DP(I)=DP(I)+TEMP
2655.5 C 30 CONTINUE
2656.5 C IF(DP(I).LT.-1.00) DP(I)=-0.900
2657.5 C 40 CONTINUE
2658.5 C
2659.5 C SAVE 'XI' VECTOR VALUES TO COMPARE WITH RECOMPUTED 'XI', AND
2660.5 C SAVE 'PIM' VECTOR VALUES FOR FUTURE USE IF EQUILIBRIUM ADJUSTMENT
2661.5 C OVERSHOTS
2662.5 C
2663.5 C DO 60 I=1,NMKT
2664.5 C OLDXI(I)=XI(I)
2665.5 C OLDPI(I)=PIM(I,M)
2666.5 C 60 CONTINUE
2667.5 C
2668.5 C -----
2669.5 C -- COMPUTE NEW PRICES --
2670.5 C -----
2671.5 C 70 CONTINUE
2672.5 C DO 90 I=1,NMKT
2673.5 C PIM(I,M)=OLDPI(I)*(1.00+DP(I))
2674.5 C 90 CONTINUE
2675.5 C
2676.5 C INDICATE THAT THE CONVERGENCE PROCESS HAS BEEN USED AGAIN
2677.5 C
2678.5 C NAGN=NAGN+1
2679.5 C
2680.5 C RETURN
2681.5 C END

```

If X exceeded OLDX fewer than NPUNT times, then the change in price, DP, calculated using the Newton's method is decreased to 25 percent of its previous value for each market price.

The subroutine PUNT is a simple 35 line program. It begins by initializing two variables.

AREA = a scalar used to determine the minimum price of the the grid area to be searched

NGRID = the number of prices to be searched in each market.

The values for PMIN and GRIDST are calculated where

PMIN = the minimum price over which the search will be conducted = $PIM/AREA$

GRIDST = the difference between search prices in each market.

The total number of price combinations is computed as $NSH=NGRIDNMKT$. PUNT then goes over each of these points systematically. For example, if there are three prices and two points per price in the grid then a simple three-dimensional rectangular search area is constructed with the price combinations examined in the order given below

<u>Search Order</u>	<u>Price Combination</u>		
	<u>P₁</u>	<u>P₂</u>	<u>P₃</u>
1	MIN	MIN	MIN
2	MIN	MIN	MAX
3	MIN	MAX	MIN
4	MIN	MAX	MAX
5	MAX	MIN	MIN
6	MAX	MIN	MAX
7	MAX	MAX	MIN
8	MAX	MAX	MAX

```

2650. C*****
2650.5 C
2651. C      SUBROUTINE PUNT
2651.5 C
2652. C*****
2652.5 C
2653. C      -- THE AREA SEARCH ALGORITHM --
2653.5 C
2654. C      THIS SUBROUTINE IS CALLED WHENEVER THE USUAL NEWTONIAN
2654.5 C      SEARCH ALGORITHM WITH VECTOR REDUCTION IS UNABLE TO FIND A SET
2655. C      OF PRICES WHICH REDUCE DISEQUILIBRIUM AFTER NPUNT TRIES.
2655.5 C
2656. C      MODEL VERSION: A.84
2656.5 C
2657. C      INPUTS
2657.5 C          INTEGER NHKT
2658. C          REAL EDRI,ESRILM,PIM
2658.5 C
2659. C      OUTPUTS
2659. C          INTEGER (NONE)
2659.5 C          REAL PIM
2660. C
2660.5 C      INTERNAL VARIABLES
2661. C          INTEGER: NGRID= FOR EACH PIM THE NUMBER OF PRICES OVER WHICH
2661.5 C                          THE SUBROUTINE WILL EXPLORE, NGRID MUST
2662. C                          BE 2 OR MORE. NSH=NUMBER OF SEARCH POINTS
2662.5 C                          IS=SEARCH POINT INDEX
2663. C                          ISP=INTEGER HOLDING VARIABLE
2663.5 C          REAL: AREA = SCALE FACTOR USED TO DETERMINE MAXIMUM
2664. C                          AND MINIMUM VALUES OF PIM TO BE EXPLORED
2664.5 C                          PMAX=PIM*AREA
2665. C                          PMIN=PIM/AREA
2665.5 C                          AREA MUST EXCEED 1.00
2666. C          GRIDST=INCREMENT EACH PRICE IS CHANGED FROM ONE
2666.5 C                  GRID STEP TO THE NEXT
2667. C          PMIN = MINIMUM PRICE SEARCHED
2667.5 C          PSTAR= PRICE VECTOR WITH MINIMUM DIVERGENCE FROM
2668. C                  EQUILIBRIUM. PIM IS SET EQUAL TO PSTAR
2668.5 C                  AT THE END OF THE SEARCH
2669. C          SP = TEMPORARY HOLDING VARIABLE
2669.5 C          U = COUNTING VARIABLE FOR DEMAND
2670. C          V = COUNTING VARIABLE FOR SUPPLY
2670.5 C          XX = SQUARED EXCESS DEMAND (U-V)**2
2671. C          XMIN = MINIMUM VALUE OF XX
2671.5 C
2672. C      SUBROUTINES CALLED: PPPP,PSPS,SSSS,DDDD
2672.5 C
2673. C      WRITTEN BY:
2673.5 C          JAE EDMUNDS
2674. C          26 OCT 1984
2674.5 C
2675. C      LATEST REVISION:
2675.5 C          NONE
2676. C*****

```

IMPLICIT STATEMENTS AND COMMON MATERIAL

```

2693.5 C
2694.5 C
2694.5 C LOCAL VARIABLES
2700.5 C
2700.5 REAL*8 AREA,GRIDST(3),PMIN(3),PSTAR(3),PSAVE(3),U,V,XX,X
2701.5 C
2701.5 C SET AREA AND GRID SIZE
2702.5 C
2702.01 PRINT 1001,PIM
2702.02 1001 FORMAT(' ',PIM: ',6G12.6)
2702.5 AREA=5.0000
2703.5 NGRID=5
2703.5 C
2703.5 C COMPUTE MINIMUM PRICES AND GRID STEPS
2704.5 C
2705.5 SP=(NGRID-1)
2705.5 DO 10 I=1,NMKT
2706.5 PMIN(I)=PIM(I,M)/AREA
2706.5 GRIDST(I)=2.00*(PIM(I,M)-PMIN(I))/SP
2707.5 10 CONTINUE
2707.5 C
2708.5 C COMPUTE NUMBER OF SEARCH POINTS AND COMMENCE SEARCH
2708.5 C
2709.5 NSH=NGRID**NMKT
2709.5 DO 60 IS=1,NSH
2710.5 C *****
2710.5 C *** SET PRICES FOR SEARCH POINT IS *****
2711.5 C *****
2711.5 DO 20 I=1,NMKT
2712.5 ISP=((IS-1)/(NGRID**I-1))-((IS-1)/(NGRID**I))*NGRID
2712.5 SP=ISP
2713.5 PIM(I,M)=PMIN(I)+GRIDST(I)*SP
2713.5 20 CONTINUE
2714.5 C *****
2714.5 C *** CALL MODEL *****
2715.5 C *****
2715.5 CALL PPPP
2716.5 CALL PSPS
2716.5 CALL SSSS
2717.5 NUB=0
2717.5 CALL DDDD
2718.5 C *****
2718.5 C *** COMPUTE DISEQUILIBRIUM METRIC *****
2719.5 C *****
2719.5 XX=0.00
2720.5 DO 40 I=1,NMKT
2720.5 U=1.00
2721.5 V=1.00
2721.5 DO 30 L=1,NL
2722.5 U=U+EDRIL(I,L)
2722.5 V=V+ESRILM(I,L,M)
2723.5 30 CONTINUE
2723.5 XX=XX+(DLOG(U)-DLOG(V))*2
2724.5 40 CONTINUE
2724.5 C *****
2725.5 C *** CHECK TO SEE IF SEARCH POINT IS MINIMUM DISEQUILIBRIUM ***
2725.5 C *****
2726.5 IF((IS.FQ.1).OR.(XX.LT.XMIN)) XMIN=XX
2726.5 DO 50 I=1,NMKT
2727.5 IF(XX.LE.XMIN) PSTAR(I)=PIM(I,M)
2727.5 50 CONTINUE
2728.5 60 CONTINUE
2728.5 C
2729.5 C ASSIGN PRICES TO PIM AND RETURN
2729.5 C
2730.5 DO 70 I=1,NMKT
2730.5 PIM(I,M)=PSTAR(I)
2731.5 70 CONTINUE
2731.5 C
2732.5 PRINT 100,PIM
2732.5 100 FORMAT(' ',PIML: ',6G12.6)
2733.5 RETURN
2733.5 END

```

The algorithm chosen takes advantage of the fact that the division operation in the integer mode uses a lowest integer function in calculating price points over which to search. (In integer mode the ratio $4/5$ is evaluated as the integer zero, while $5/5$ or $6/5$ are evaluated as the integer one.)

The model then calls the model, subroutines PPPP, PSPS, SSSS, and DDDD, and then evaluates the case's proximity to equilibrium. The convergence metric, XX, is calculated for each price combination and the metric compared to the previous lowest value XMIN. If XX is smaller than XMIN then that set of prices is saved as PSTAR and becomes the new XMIN.

At the end of the run PIM is assigned the values of PSTAR and PIM becomes the new iterative value for the search procedure. The subroutine then returns to REVISE and the model goes back to using the Newtonian method until it becomes "stuck" again.

INPUT MODE CHANGES

Numerous small changes were made in the way data was entered. Many had no effect on the internal workings of the model, while others required adjustments in the way data was handled or a translation from the new variable definition to the old. To facilitate a complete understanding of the changes a side-by-side comparison of the Version B.82 input format with that of version A.84 follows.

Transportation Costs and Initial Price Estimates

This material has been reformatted in A.84. Transport costs are entered on a separate line from world market prices and each year has an initial guess. Thus the model need not begin the search each period with the previous period's solution prices.

Model Version A.84

Model Version B.82

TRI--TRANSPORTATION COSTS FOR TRADED FUELS
 PIN--INITIAL ESTIMATE OF PRICES FOR TRADED FUELS BY FUEL
 AND PERIOD
 (UNITS=1975 DOLLARS PER GJ (GIGAJoule))

OIL	GAS	COAL	TRI
0.1397	2.3458	0.5121	PIN M=1
1.8398	0.5256	0.5121	PIN M=2
3.01	0.34	0.63	PIN M=3
4.64	1.42	0.65	PIN M=4
5.63	2.29	0.87	PIN M=5
6.69	3.19	1.44	PIN M=6
6.70	3.43	1.43	

PRICE DATA DEVELOPMENT
 FOSSIL FUELS
 WORLD PRICES (PI) AND TRANSPORT COSTS (TRI)
 (IN 1975 DOLLARS PER GJ (GIGAJoule))

OIL	GAS	COAL
PI	TRI	PI
1.8398	0.1397	0.4256
		2.8458
		0.5121

IMPORT/EXPORT STATUS (NXIL)
 (NXIL=1 INDICATES EXPORTER; NXIL=-1, IMPORTER.)

OIL	GAS	COAL	REGION
-1	1	1	1 US
-1	-1	-1	2 WEUR+CAN
-1	-1	-1	3 JAPN
1	1	1	4 EUSSR
-1	1	1	5 ACENP
1	1	-1	6 MIDEAST
1	1	-1	7 AFR
1	1	-1	8 LA
-1	1	-1	9 SEASIA

As pointed out earlier all of the NXIL's were removed with the introduction of the new model solution criteria.

Tariffs and Taxes. The tariff (TXILM) and final consumption tax (TXJLM) enter the model just as before. The only change is a quantitative one. The 1975 values for TXILM have been adjusted to account for the fact that the "landed" fuel cost of marketed fuels depended on whether or not a region paid transport costs or not. Since this question was resolved arbitrarily, an adjustment for 1975 was necessary to avoid having to completely recalibrate the 1975 model base.

Population and GNP. As discussed earlier the import matrices for the Version A.84 have been reduced from the rather elaborate series of population and GNP indices with base year values to two smaller tables of population, measured in natural units, and a table with base GNP's and a labor productivity assumptions. This simplification was discussed in detail in an earlier section of this appendix.

Refinery and Electric Power Coefficients. There is no difference in the way refinery and electric power coefficients are entered into the model.

1.0000	1.0000	AFR
1.0000	1.0000	LA
1.0000	1.0000	SEE AS
2075	2100	REGION
1.0000	1.0000	USA
1.0000	1.0000	CANADA
1.0000	1.0000	JANZ
1.0000	1.0000	EUSSR

ELECTRICITY -	
1975	2000
1.0000	1.00
1.0000	1.00
1.0000	1.00
1.0000	1.00
1.0000	1.00

2025	2050
1.0000	1.0000
1.0000	1.0000
1.0000	1.0000
1.0000	1.0000

2675	2100	REGION
1.0000	1.0000	USA
1.0000	1.0000	CANADA
1.0000	1.0000	JANZ
1.0000	1.0000	EUSSR

1.0000	1.00
1.0000	1.00
1.0000	1.00
1.0000	1.00
1.0000	1.00

1.0000	1.0000
1.0000	1.0000
1.0000	1.0000
1.0000	1.0000
1.0000	1.0000

1.0000	1.0000	ACENP
1.0000	1.0000	HIDEAS
1.0000	1.0000	AFR
1.0000	1.0000	LA
1.0000	1.0000	SEE AS

Model Version A.84

model Version B.82

POPULATION (ZLM)
UNITS=THOUSANDS OF PERSONS

1950	1975	2000	2025	2050	2075	2100
152271.	214000.	254000.	282000.	288000.	292000.	292000.
300245.	405000.	476000.	528000.	553000.	562000.	562000.
36307.	123000.	134000.	164000.	167000.	169000.	169000.
286136.	395000.	472000.	515000.	523000.	541000.	541000.
590533.	911000.	1248000.	1491000.	1612000.	1547000.	1647000.
39045.	91000.	147000.	199000.	232000.	241000.	241000.
222073.	399000.	597000.	941000.	1101000.	1150000.	1150000.
165754.	313000.	540000.	715000.	821000.	849000.	849000.
652750.	1130000.	1904000.	2515000.	2638000.	2995000.	2995000.

LABOR PRODUCTIVITY GROWTH RATE (UNITS=ANNUAL RATE)
AND BASE GNP (UNITS=MILLIONS 1975 US DOLLARS)

LAEDR	BASE	
PRODUCTIVITY	GNP	
0.017	1513590.	USA
0.017	1017860.	NEURECAN
0.017	586400.	JANZ
0.017	965400.	EUSSR
0.029	323600.	ASENP
0.029	128410.	MIDEAST
0.029	154590.	AFR
0.029	315490.	LA
0.029	233620.	SEASIA

1975 ACTUAL POPULATION (ZL, THOUSANDS) AND BASE GNP (MIL T

UNITED STATES		OECD REGIONS		OECD PACIFIC	
POPULATION	GNP	POPULATION	GNP	POPULATION	GNP
213925.	1519890.	405029.	1817860.	127961.	58640
CENTRALLY PLANNED AND MIDDLE EAST REGIONS					
EUSSR		ACENPL		MIDEAST	
POPULATION	GNP	POPULATION	GNP	POPULATION	GNP
394582.	966400.	910964.	323600.	81371.	13841
DEVELOPING COUNTRY REGIONS					
AFRICA		LATIN AMERICA		SOUTH & EAST A	
POPULATION	GNP	POPULATION	GNP	POPULATION	GNP
399370.	154690.	312631.	315490.	1129957.	23362

POPULATION (ZLM) AND BASE ECONOMIC ACTIVITY (GNP)
(POPULATION AND GNP ARE READ IN AS AN INDEX, 1975=1.00)

UNITED STATES		OECD REGIONS		OECD PACIFIC	
POPULATION	GNP	POPULATION	GNP	POPULATION	GNP
1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.1890	1.8770	1.1760	1.9780	1.2010	2.70
1.3170	3.0210	1.3030	3.5340	1.2790	5.43
1.3470	4.5050	1.3450	5.7090	1.3050	9.12
1.3664	6.6990	1.3672	8.4900	1.3176	13.23
1.3664	9.7200	1.3672	12.3180	1.3176	19.20
CENTRALLY PLANNED AND MIDDLE EAST REGIONS					
EUSSR		ACENPL		MIDEAST	
POPULATION	GNP	POPULATION	GNP	POPULATION	GNP
1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.1960	1.8150	1.3700	2.8650	1.8030	3.64
1.3080	2.9430	1.6450	5.4680	2.4480	8.95
1.3510	4.4420	1.7700	10.3350	2.8470	18.04
1.3720	6.6060	1.8081	17.3760	2.9595	30.33
1.3720	9.5850	1.8081	28.5070	2.9595	49.77
DEVELOPING COUNTRY REGIONS					
AFRICA		LATIN AMERICA		SOUTH & EAST ASI	
POPULATION	GNP	POPULATION	GNP	POPULATION	GNP
1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.7450	3.0690	1.7280	3.4750	1.6850	3.07
2.3610	7.3270	2.2980	9.0050	2.2260	7.10
2.7580	13.8060	2.6310	16.3950	2.5560	13.50
2.8807	23.7870	2.7144	28.2480	2.6504	23.26
2.8807	39.0250	2.7144	46.3430	2.6504	38.16

REFINERY COEFFICIENTS (GID AND HLI)

"GJ" IS A CONVERSION EFFICIENCY, THE RATIO OF JOULES OF PRIMARY ENERGY IN TO JOULES OF ENERGY PRODUCT OUT (EXCLUSIVE OF FUELS USED AS ENERGY BY THE REFINERY). IT IS APPROXIMATED AS 1.
 "M" IS A MARK-UP COST, ACCOUNTING FOR COST OF REFINING AND DISTRIBUTING ENERGY PRODUCTS.

ELECTRICITY GENERATION COEFFICIENTS (GUI, MJ/L, AND RUI)
 "GUI" IS A GENERATION EFFICIENCY COEFFICIENT — THE RATIO OF JOULES OF ENERGY IN TO JOULES OF ELECTRICITY OUT. BY DEFINITION, GUI=1 FOR NUCLEAR, HYDRO, AND SOLAR.
 "MJ/L" REFLECTS NONENERGY COSTS IN 1975 DOLLARS PER GJ.
 "RUI" IS A LOGIT SUBSTITUTION PARAMETER GOVERNING THE RESPONSE OF UTILITIES TO PRICE INCREASES FOR A GIVEN TECHNOLOGY — HYDRO ENT: AS A FIXED AMOUNT.

FUEL						PARAME
OIL	GAS	COAL	NUCLEAR	SOLAR	HYDRO	
-3.6580	-3.6580	-3.3250	-1.0970	-1.0970	-1.0970	GU
4.5330	4.5052	4.8660	1.7000	1.7000	1.7000	MU1 L
4.5330	4.5052	4.8660	1.7000	1.7000	1.7000	MU1 L
4.5330	4.5052	4.8660	1.7000	1.7000	1.7000	MU1 L
4.5330	4.5052	5.8630	1.7000	1.7000	1.7000	MU1 L
4.5330	4.5052	5.8630	1.7000	1.7000	1.7000	MU1 L
4.5330	4.5052	5.8630	1.7000	1.7000	1.7000	MU1 L
4.5330	4.5052	5.8630	1.7000	1.7000	1.7000	MU1 L
4.5330	4.5052	5.8630	1.7000	1.7000	1.7000	MU1 L
4.5330	4.5052	5.8630	1.7000	1.7000	1.7000	MU1 L
-3.0000	-3.0000	-3.0000	-3.0000	-3.0000		RU1

PAUL — ELECTRICITY GENERATION COEFFICIENTS
(PAUL IS A MULTIPLICATIVE FACTOR WHICH ADJUSTS THE REFINED
FOSSILE FUEL PRICE TO ACCOUNT FOR DIFFERENT FUEL TYPE (E.G.
RESIDUAL US GASOLINE) AND DISTRIBUTION COSTS.)

		FUEL		REGION
	LIQUID	GAS	SOLID	
C.	4830	C. 7330	1.00	US
C.	5747	0.0195	0.8293	NEUR+CAN
C.	5243	0.9395	1.00	DECD PAC
C.	4009	1.00	1.00	EUSSR
C.	4000	-	1.00	ACENP
C.	3593	1.00	1.00	MIDEAST
C.	4195	1.00	1.00	AFRICA
C.	4013	1.00	1.00	L AMER
C.	6059	1.00	1.00	SEE ASIA

BSU1LM: ELECTRIC UTILITY FUEL SHARE WEIGHTS,
BY PERIOD, FUEL AND REGION

1975					
OIL	GAS	COAL	NUCLEAR	SOLAR	REGION
Q. 0915	Q. 0274	Q. 2000	Q. 0346	Q. 0253	US
Q. 1480	Q. 0694	Q. 2000	Q. 0192	Q. 0172	WEUR+CAN
Q. 1937	Q. 2000	Q. 0458	Q. 0082	Q. 0056	OECD PAC
Q. 1157	Q. 0565	Q. 2000	Q. 0060	Q. 0060	EUSSR
Q. 0547	Q. 0074	Q. 2000	Q. 0013	Q. 0011	ACEN#
Q. 2000	Q. 0408	Q. 0	Q. 0001	Q. 0	MIDEAST
Q. 1851	Q. 0128	Q. 2000	Q. 0011	Q. 0009	AFRICA
Q. 2000	Q. 0453	Q. 0319	Q. 0080	Q. 0061	L AMER
Q. 1158	Q. 0007	Q. 2000	Q. 0039	Q. 0036	SEE ASIA

BSU1LM: YEAR 2000

GIL	GAS	COAL	NUCLEAR	SOLAR	REGION
Q. 0181	0.0288	Q. 2000	Q. 0702	0.0651	US
Q. 1403	0.0542	Q. 2000	Q. 0718	0.0458	NEUR+CAN
Q. 2000	0.0467	Q. 1178	Q. 0433	0.0347	CECD PAC
Q. 2000	0.1359	Q. 2000	Q. 0375	0.0370	EUSSR
Q. 1346	0.0062	Q. 2000	Q. 0161	0.0062	ACENP
Q. 2000	0.1102	Q. 0200	Q. 0045	0.0045	MIDEAST
Q. 2000	0.0276	Q. 2000	Q. 0148	0.0134	AFRICA
Q. 2000	0.1176	Q. 0951	Q. 0428	0.0376	L AMER
Q. 1660	0.0118	Q. 2000	Q. 0291	0.0280	SEE ASIA

BSUILM8 YEAR 2025

OIL	GAS	COAL	NUCLEAR	SOLAR	REGION
Q. 0.050	Q. 12.74	Q. 2000	Q. 1754	Q. 2000	US
Q. 2000	Q. 2000	Q. 2000	Q. 2000	Q. 2000	NEUR+CAN
Q. 2000	Q. 2000	Q. 2000	Q. 2000	Q. 2000	OECD PAC
Q. 2000	Q. 2000	Q. 2000	Q. 2000	Q. 2000	EURO
Q. 2000	Q. 1000	Q. 2000	Q. 2000	Q. 0.053	ACENP
Q. 2000	Q. 2000	Q. 1000	Q. 2000	Q. 2000	MIDEAST
Q. 2000	Q. 2000	Q. 2000	Q. 2000	Q. 2000	AFRICA
Q. 2000	Q. 2000	Q. 2000	Q. 2000	Q. 2000	L AMER
Q. 2000	Q. 2000	Q. 2000	Q. 2000	Q. 2000	SEE ASIA

BSU/LN: YEAR 2090

OIL	GAS	COAL	NUCLEAR	SOLAR	REGION
Q-1375	Q-2000	Q-2000	Q-2000	Q-2000	US
Q-2000	Q-2000	Q-2000	Q-2000	Q-2000	NEUR+CAN
Q-2000	Q-2000	Q-2000	Q-2000	Q-2000	OECD PAC
Q-2000	Q-2000	Q-2000	Q-2000	Q-2000	SUR
Q-2000	Q-2000	Q-2000	Q-2000	Q-2000	ACENP
Q-2000	Q-2000	Q-1000	Q-2000	Q-2000	NICEAST
Q-2000	Q-2000	Q-2000	Q-2000	Q-2000	AFR
Q-2000	Q-2000	Q-2000	Q-2000	Q-2000	L AMER
Q-2000	Q-2000	Q-2000	Q-2000	Q-2000	SEE ASIA

Model Version A.84

Model Version B.82

BSUFLM:	YEAR 2075				
	GAS	COAL	NUCLEAR	SOLAR	REGION
C.1275	0.2000	0.2000	0.2000	0.2000	US
C.2000	0.2000	0.2000	0.2000	0.2000	WEUR+CAN
C.2000	0.2000	0.2000	0.2000	0.2000	DECD PAC
C.2000	0.2000	0.2000	0.2000	0.2000	EUSSR
C.2000	0.2000	0.2000	0.2000	0.2000	ACENP
C.2000	0.2000	0.2000	0.2000	0.2000	MIDEAST
C.2000	0.2000	0.2000	0.2000	0.2000	AFR
C.2000	0.2000	0.2000	0.2000	0.2000	L AMER
C.2000	0.2000	0.2000	0.2000	0.2000	SEE ASIA

BSUFLM:	YEAR 2100				
	GAS	COAL	NUCLEAR	SOLAR	REGION
C.1275	0.2000	0.2000	0.2000	0.2000	US
C.2000	0.2000	0.2000	0.2000	0.2000	WEUR+CAN
C.2000	0.2000	0.2000	0.2000	0.2000	DECD PAC
C.2000	0.2000	0.2000	0.2000	0.2000	EUSSR
C.2000	0.2000	0.2000	0.2000	0.2000	ACENP
C.2000	0.2000	0.2000	0.2000	0.2000	MIDEAST
C.2000	0.2000	0.2000	0.2000	0.2000	AFR
C.2000	0.2000	0.2000	0.2000	0.2000	L AMER
C.2000	0.2000	0.2000	0.2000	0.2000	SEE ASIA

BSUFLM:	YEAR 2075					
	OIL	GAS	COAL	NUCLEAR	SOLAR	RE
C.1275	0.2000	0.2000	0.2000	0.2000	0.2000	US
C.2000	0.2000	0.2000	0.2000	0.2000	0.2000	WE
C.2000	0.2000	0.2000	0.2000	0.2000	0.2000	DE
C.2000	0.2000	0.2000	0.2000	0.2000	0.2000	EU
C.2000	0.2000	0.2000	0.2000	0.2000	0.2000	AC
C.2000	0.2000	0.2000	0.2000	0.2000	0.2000	MI
C.2000	0.2000	0.2000	0.2000	0.2000	0.2000	AF
C.2000	0.2000	0.2000	0.2000	0.2000	0.2000	L
C.2000	0.2000	0.2000	0.2000	0.2000	0.2000	SC

BSUFLM:	YEAR 2100					
	OIL	GAS	COAL	NUCLEAR	SOLAR	RE
C.1275	0.2000	0.2000	0.2000	0.2000	0.2000	US
C.2000	0.2000	0.2000	0.2000	0.2000	0.2000	WE
C.2000	0.2000	0.2000	0.2000	0.2000	0.2000	DE
C.2000	0.2000	0.2000	0.2000	0.2000	0.2000	EU
C.2000	0.2000	0.2000	0.2000	0.2000	0.2000	AC
C.2000	0.2000	0.2000	0.2000	0.2000	0.2000	MI
C.2000	0.2000	0.2000	0.2000	0.2000	0.2000	AF
C.2000	0.2000	0.2000	0.2000	0.2000	0.2000	L
C.2000	0.2000	0.2000	0.2000	0.2000	0.2000	SC

End-Use Energy Efficiency. A tremendous amount of data was compressed by entering the rate of exogenous energy efficiency, TXJKLM, as a rate TXL, rather than directly as the sector, fuel, region period specific variable TXJKLM. This results in a transformation in the code.

The new variables, TXL, the rate of technological change by region and sector, and a holding variable TECH, local to the subroutine DDDD were added, TECH replaces TXJKLM in the code as it appears in DDDD and is calculated simply as

$$\text{TECH} = (1.00 + \text{TKL}(K,L))^{**T}$$

where T is the number of years elapsed from the base year.

Model Version A.84

model Version B.82

TECHNOLOGICAL CHANGE (TJCLM)

TECHNOLOGICAL CHANGE IS READ IN AS AN INDEX WITH 1975=1. AN INCREASING VALUE OVER TIME IMPLIES ENERGY SAVINGS PER UNIT OUTPUT

OECD REGIONS

UNITED STATES -- RESIDENTIAL/COMMERCIAL

LIQUIDS	GASES	SOLIDS	ELEC	YEAR
1.0000	1.0000	1.0000	1.0000	1975
1.0000	1.0000	1.0000	1.0000	2000
1.0000	1.0000	1.0000	1.0000	2025
1.0000	1.0000	1.0000	1.0000	2050
1.0000	1.0000	1.0000	1.0000	2075
1.0000	1.0000	1.0000	1.0000	2100

UNITED STATES -- INDUSTRIAL

LIQUIDS	GASES	SOLIDS	ELEC	YEAR
1.0000	1.0000	1.0000	1.0000	1975
1.2800	1.2800	1.2800	1.2800	2000
1.6400	1.6400	1.6400	1.6400	2025
2.1100	2.1100	2.1100	2.1100	2050
2.7000	2.7000	2.7000	2.7000	2075
3.4700	3.4700	3.4700	3.4700	2100

UNITED STATES -- TRANSPORTATION

LIQUIDS	GASES	SOLIDS	ELEC	YEAR
1.0000	1.0000	1.0000	1.0000	1975
1.0000	1.0000	1.0000	1.0000	2000
1.0000	1.0000	1.0000	1.0000	2025
1.0000	1.0000	1.0000	1.0000	2050
1.0000	1.0000	1.0000	1.0000	2075
1.0000	1.0000	1.0000	1.0000	2100

EUR+CAN -- RESIDENTIAL/COMMERCIAL

LIQUIDS	GASES	SOLIDS	ELEC	YEAR
1.0000	1.0000	1.0000	1.0000	1975
1.0000	1.0000	1.0000	1.0000	2000
1.0000	1.0000	1.0000	1.0000	2025
1.0000	1.0000	1.0000	1.0000	2050
1.0000	1.0000	1.0000	1.0000	2075
1.0000	1.0000	1.0000	1.0000	2100

EUR+CAN -- INDUSTRIAL

LIQUIDS	GASES	SOLIDS	ELEC	YEAR
1.0000	1.0000	1.0000	1.0000	1975
1.2800	1.2800	1.2800	1.2800	2000
1.6400	1.6400	1.6400	1.6400	2025
2.1100	2.1100	2.1100	2.1100	2050
2.7000	2.7000	2.7000	2.7000	2075
3.4700	3.4700	3.4700	3.4700	2100

EUR+CAN -- TRANSPORTATION

LIQUIDS	GASES	SOLIDS	ELEC	YEAR
1.0000	1.0000	1.0000	1.0000	1975
1.0000	1.0000	1.0000	1.0000	2000
1.0000	1.0000	1.0000	1.0000	2025
1.0000	1.0000	1.0000	1.0000	2050
1.0000	1.0000	1.0000	1.0000	2075
1.0000	1.0000	1.0000	1.0000	2100

OECD PAC -- RESIDENTIAL/COMMERCIAL

LIQUIDS	GASES	SOLIDS	ELEC	YEAR
1.0000	1.0000	1.0000	1.0000	1975
1.0000	1.0000	1.0000	1.0000	2000
1.0000	1.0000	1.0000	1.0000	2025
1.0000	1.0000	1.0000	1.0000	2050
1.0000	1.0000	1.0000	1.0000	2075
1.0000	1.0000	1.0000	1.0000	2100

OECD PAC -- INDUSTRIAL

LIQUIDS	GASES	SOLIDS	ELEC	YEAR
1.0000	1.0000	1.0000	1.0000	1975
1.2800	1.2800	1.2800	1.2800	2000
1.6400	1.6400	1.6400	1.6400	2025
2.1100	2.1100	2.1100	2.1100	2050
2.7000	2.7000	2.7000	2.7000	2075
3.4700	3.4700	3.4700	3.4700	2100

OECD PAC -- TRANSPORTATION

LIQUIDS	GASES	SOLIDS	ELEC	YEAR
1.0000	1.0000	1.0000	1.0000	1975
1.0000	1.0000	1.0000	1.0000	2000
1.0000	1.0000	1.0000	1.0000	2025
1.0000	1.0000	1.0000	1.0000	2050
1.0000	1.0000	1.0000	1.0000	2075
1.0000	1.0000	1.0000	1.0000	2100

TKL--RATE OF END-USE ENERGY EFFICIENCY IMPROVEMENT BY SECTOR AND REGION
UNITS=NONE

PES/COM	INDUSTRY	TRANSPORT	REGION
0.01	0.01	0.01	1=USA
0.01	0.01	0.01	2=EUR+CAN
0.01	0.01	0.01	3=OECD PAC

NON-OECD REGIONS	REGION
0.01	4=EUSSR
0.01	5=ACENP
0.01	6=MIDEAST
0.01	7=AFRICA
0.01	8=L AMER
0.01	9=SEE ASIA

Model Version B.82

NON-OECD REGIONS
(NON-OECD REGIONS ARE NOT DIFFERENTIATED BY SECTOR)

LIQUIDS	GASES	EUSSR SOLIDS	EL EC	YEAR
1.0000	1.0000	1.0000	1.0000	1975
1.1100	1.1100	1.1100	1.1100	2000
1.2600	1.2600	1.2600	1.2600	2025
1.4400	1.4400	1.4400	1.4400	2050
1.6800	1.6800	1.6800	1.6800	2075
1.9900	1.9900	1.9900	1.9900	2100

LIQUIDS	GASES	ACENP SOLIDS	EL EC	YEAR
1.0000	1.0000	1.0000	1.0000	1975
1.1100	1.1100	1.1100	1.1100	2000
1.2600	1.2600	1.2600	1.2600	2025
1.4400	1.4400	1.4400	1.4400	2050
1.6800	1.6800	1.6800	1.6800	2075
1.9900	1.9900	1.9900	1.9900	2100

LIQUIDS	GASES	MIDEAST SOLIDS	EL EC	YEAR
1.0000	1.0000	1.0000	1.0000	1975
1.1100	1.1100	1.1100	1.1100	2000
1.2600	1.2600	1.2600	1.2600	2025
1.4400	1.4400	1.4400	1.4400	2050
1.6800	1.6800	1.6800	1.6800	2075
1.9900	1.9900	1.9900	1.9900	2100

LIQUIDS	GASES	AFR SOLIDS	EL EC	YEAR
1.0000	1.0000	1.0000	1.0000	1975
1.1100	1.1100	1.1100	1.1100	2000
1.2600	1.2600	1.2600	1.2600	2025
1.4400	1.4400	1.4400	1.4400	2050
1.6800	1.6800	1.6800	1.6800	2075
1.9900	1.9900	1.9900	1.9900	2100

LIQUIDS	GASES	LA SOLIDS	EL EC	YEAR
1.0000	1.0000	1.0000	1.0000	1975
1.1100	1.1100	1.1100	1.1100	2000
1.2600	1.2600	1.2600	1.2600	2025
1.4400	1.4400	1.4400	1.4400	2050
1.6800	1.6800	1.6800	1.6800	2075
1.9900	1.9900	1.9900	1.9900	2100

LIQUIDS	GASES	SEASIA SOLIDS	EL EC	YEAR
1.0000	1.0000	1.0000	1.0000	1975
1.1100	1.1100	1.1100	1.1100	2000
1.2600	1.2600	1.2600	1.2600	2025
1.4400	1.4400	1.4400	1.4400	2050
1.6800	1.6800	1.6800	1.6800	2075
1.9900	1.9900	1.9900	1.9900	2100

Supply Parameters. Changes in the supply module were massive.

Changes were so great that little comparable material remains, only gas flaring and hydroelectric parameters remain as before.

In Version B.82 conventional oil and gas were handled separately. Parameters were entered for a logistics curve and mideast production was entered separately. In Version A.84 all fossil fuels and nuclear power are treated similarly and parameters are entered first.

Both versions then attended to gas flaring and hydroelectric power.

Data Inputs: Supply Parameters

Model Version A.84

RIGISL--RESOURCES BY GRADE AND REGION
(UNITS=EXAJOULES)

GRADE: IG=1

CONV OIL	CONV GAS	COAL	UNCON OIL	NUCLEAR	REGION
77.	570.	7954.	4691.	109.	1=USA
100.	434.	2439.	2142.	200.	2=NEUR+CAN
3.	72.	1891.	1564.	97.	3=OECD PAC
190.	1324.	15336.	4294.	267.	4=EUSSR
62.	179.	4054.	2147.	128.	5=ACENP
400.	1054.	2.	537.	2.	6=MIDEAST
130.	346.	607.	6411.	842.	7=AFRICA
159.	363.	141.	2205.	1010.	8=L AMER
25.	190.	365.	1510.	21.	9=SEE ASIA

GRADE: IG=2

CONV OIL	CONV GAS	COAL	UNCON OIL	NUCLEAR	REGION
221.	237.	3763.	3170.	594.	1=USA
230.	179.	3015.	4189.	1098.	2=NEUR+CAN
9.	72.	2319.	3057.	519.	3=OECD PAC
550.	547.	18590.	8337.	1426.	4=EUSSR
151.	73.	4970.	4187.	682.	5=ACENP
1000.	435.	2.	1049.	12.	6=MIDEAST
436.	142.	743.	12532.	2358.	7=AFRICA
334.	151.	143.	6286.	5388.	8=L AMER
70.	56.	447.	3148.	113.	9=SEE ASIA

GRADE: IG=3

CONV OIL	CONV GAS	COAL	UNCON OIL	NUCLEAR	REGION
441.	510.	13874.	98173.	100000.	1=USA
577.	333.	4284.	40266.	100000.	2=NEUR+CAN
17.	53.	5234.	29391.	100000.	3=OECD PAC
1095.	1007.	23578.	80708.	100000.	4=EUSSR
267.	135.	7062.	40344.	100000.	5=ACENP
890.	302.	3.	10008.	100000.	6=MIDEAST
771.	253.	1053.	120563.	100000.	7=AFRICA
679.	279.	211.	60252.	100000.	8=L AMER
123.	121.	625.	30266.	100000.	9=SEE ASIA

GRADE: IG=4

CONV OIL	CONV GAS	COAL	UNCON OIL	NUCLEAR	REGION
373.	582.	19012.	254516.	100000.	1=USA
488.	377.	5871.	120797.	100000.	2=NEUR+CAN
14.	61.	4513.	38173.	100000.	3=OECD PAC
925.	1150.	32311.	242123.	100000.	4=EUSSR
204.	155.	9678.	121062.	100000.	5=ACENP
3650.	316.	4.	30256.	100000.	6=MIDEAST
591.	301.	1457.	361512.	100000.	7=AFRICA
520.	318.	283.	180755.	100000.	8=L AMER
94.	139.	871.	90797.	100000.	9=SEE ASIA

GRADE: IG=5

CONV OIL	CONV GAS	COAL	UNCON OIL	NUCLEAR	REGION
232.	0.	19012.	0.	0.	1=USA
382.	0.	5871.	0.	0.	2=NEUR+CAN
11.	0.	4513.	0.	0.	3=OECD PAC
725.	0.	32311.	0.	0.	4=EUSSR
154.	0.	9678.	0.	0.	5=ACENP
1460.	0.	4.	0.	0.	6=MIDEAST
1444.	0.	1450.	0.	0.	7=AFRICA
391.	0.	283.	0.	0.	8=L AMER
371.	0.	871.	0.	0.	9=SEE ASIA

CIGIS--MINIMUM EXTRACTION COSTS BY GRADE AND FUEL
FINAL COST IS THE MAXIMUM EXTRACTION COST AT
RESOURCE EXHAUSTION
(UNITS=1975 DOLLARS/GIGAJoule)

CONV OIL	CONV GAS	COAL	UNCON OIL	NUCLEAR	GRADE
0.16	0.30	0.30	3.80	6.33	IG=1
0.22	1.30	0.40	7.60	15.20	IG=2
0.80	2.30	0.80	12.80	21.80	IG=3
1.10	1.90	1.70	22.60	22.30	IG=4
1.10	15.00	5.70	51.00	23.00	IG=5
1.20	16.00	5.80	52.00	24.00	FINAL

VISL--ENVIRONMENTAL COST AMOUNTS BY REGION AND FUEL
(UNITS=1975 DOLLARS/GIGAJoule)

CONV OIL	CONV GAS	COAL	UNCON OIL	NUCLEAR	REGION
0.0	0.0	1.60	1.30	10.00	1=USA
0.0	0.0	1.60	1.30	10.00	2=NEUR+CAN
0.0	0.0	1.60	1.30	10.00	3=OECD PAC
0.0	0.0	0.80	0.90	10.00	4=EUSSR
0.0	0.0	0.30	0.90	10.00	5=ACENP
0.0	0.0	0.30	0.90	10.00	6=MIDEAST
0.0	0.0	0.90	0.90	10.00	7=AFRICA
0.0	0.0	0.80	0.30	10.00	8=L AMER
0.0	0.0	0.80	0.90	10.00	9=SEE ASIA

RIL--PRICE ELASTICITY OF SUPPLY, EVALUATED AT THE PRICE
(BY SUPPLY TYPE AND REGION)

CONV OIL	CONV GAS	COAL	UNCON OIL	REGION
1.0	1.0	1.0	1.0	1=USA
1.0	1.0	1.0	1.0	2=NEUR+CAN
1.0	1.0	1.0	1.0	3=OECD PAC
1.0	1.0	1.0	1.0	4=EUSSR
1.0	1.0	1.0	1.0	5=ACENP
1.0	1.0	1.0	1.0	6=MIDEAST
1.0	1.0	1.0	1.0	7=AFRICA
1.0	1.0	1.0	1.0	8=L AMER
1.0	1.0	1.0	1.0	9=SEE ASIA

Model Version B.82

PARAMETER VALUES FOR RESOURCE CONSTRAINED SUPPLY TECHNOLOGIES
EXHAUSTABLE, RESOURCE CONSTRAINED TECHNOLOGIES
PARAMETERS ARE THOSE OF LOGISTICS FUNCTION -- "AIL" IS THE
OF CUMULATIVE PRODUCTION OF CONVENTIONAL FUEL (IN REGION
THE BASE PERIOD. "BIL" IS THE YEAR OF PEAK PRODUCTION ON
AND IS TRANSFORMED TO THE LOGISTICS CURVE PARAMETER B. (B
WHERE T IS THE DATE OF MAXIMUM PRODUCTION.
"RESIL" IS THE TOTAL RESOURCE IN EXAJOULES.

AIL	BIL	RESIL	AIL	BIL	RESIL
634.5850	1983.1200	1605.5310	514.1000	1988.9500	1582.5000
54.5690	2029.8100	998.0960	76.0960	2024.7600	1087.7050
5.2300	1989.3500	34.5110	0.0980	2036.5500	158.2500
303.8180	2004.1200	2047.4570	148.9270	2021.3900	2557.6680
37.4550	2015.6100	680.1270	5.2670	2036.7800	403.0100
482.6890	1994.4400	3854.0520	55.7290	2026.3800	2088.7840
160.1910	2012.5800	1647.0500	18.2840	2037.5200	796.5250
258.8050	2000.4400	1449.9540	46.5840	2017.1500	902.0250
52.1550	1994.0400	367.1190	12.2550	2010.9000	374.6250

EASTIN -- EXOGENOUS MIDEAST SUPPLIES OF OIL AND GAS (UNITS=EXAJOULES)

1975	2000	2025	2050	2075	2100
42.5000	37.0000	37.0000	37.0000	5.0000	0.0
10.5500	10.5500	15.0000	30.0000	15.0000	10.0000

Model Version A.84

Model Version B.82

STISL--RATE OF TECHNOLOGICAL CHANGE BY SUPPLY TYPE
AND REGION

NUV OIL	CONV GAS	COAL	UNCON OIL	NUCLEAR	REGION
0.005	0.005	0.005	0.005	0.005	1=USA
0.005	0.005	0.005	0.005	0.005	2=NEUR+CAN
0.005	0.005	0.005	0.005	0.005	3=OECD PAC
0.005	0.005	0.005	0.005	0.005	4=EUSSR
0.005	0.005	0.005	0.005	0.005	5=ACENP
0.005	0.005	0.005	0.005	0.005	6=MIDEAST
0.005	0.005	0.005	0.005	0.005	7=AFRICA
0.005	0.005	0.005	0.005	0.005	8=L AMER
0.005	0.005	0.005	0.005	0.005	9=SEE ASIA

BESIL--MINIMUM LEVEL OF SHORT-TERM SUPPLY BY TYPE
AND REGION

NUV OIL	CONV GAS	COAL	UNCON OIL	NUCLEAR	REGION
0.03	0.03	0.03	0.03	0.03	1=USA
0.03	0.03	0.03	0.03	0.03	2=NEUR+CAN
0.03	0.03	0.03	0.03	0.03	3=OECD PAC
0.03	0.03	0.03	0.03	0.03	4=EUSSR
0.03	0.03	0.03	0.03	0.03	5=ACENP
0.03	0.03	0.03	0.03	0.03	6=MIDEAST
0.03	0.03	0.03	0.03	0.03	7=AFRICA
0.03	0.03	0.03	0.03	0.03	8=L AMER
0.03	0.03	0.03	0.03	0.03	9=SEE ASIA

ESFIL--INITIAL ESTIMATE OF ENERGY SUPPLY
BY FUEL, REGION, AND PERIOD
(UNITS=EXAJOULES/YR)

YEAR=1975

NUV OIL	CONV GAS	COAL	UNCON OIL	NUCLEAR	REGION
20.41	20.73	17.18	0.0	0.52	1=USA
4.77	8.98	9.50	0.0	0.58	2=NEUR+CAN
0.96	0.31	0.57	0.0	0.09	3=OECD PAC
22.77	11.91	12.77	0.0	0.07	4=EUSSR
3.23	1.14	1.51	0.0	0.00	5=ACENP
42.35	1.21	0.03	0.0	0.00	6=MIDEAST
10.53	0.39	0.18	0.0	0.00	7=AFRICA
3.92	1.55	0.39	0.0	0.01	8=L AMER
1.79	0.75	2.68	0.0	0.01	9=SEE ASIA

AS FLARING

"FLRL1" IS THE FLARING RATE IN 1975, "FLRL2" IS THE ULTIMATE
FLARING RATE, AND "FLRL3" IS THE NUMBER OF YEARS TO REACH "FLRL2"
THE MODEL EXPONENTIALLY INTERPOLATES BETWEEN THE RATES.

FLRL1	FLRL2	FLRL3	REGION
0.55	0.50	10.0	US
0.70	0.50	10.0	NEUR+CAN
0.05	0.10	10.0	JANZ
0.49	0.50	10.0	EUSSR
107	0.50	10.0	ACENP
727	0.50	50.0	MIDEAST
736	0.50	50.0	AFR
523	0.50	28.0	LA
349	0.50	15.0	SEASIA

RENEWABLE RESOURCE CONSTRAINED TECHNOLOGIES

PARAMETERS INCLUDE LOGISTICS FUNCTION PARAMETERS, COST, AND SHARE
DATA. "HYDROIL" ORIENTS THE PRODUCTION PATH IN TIME; "HYDRO2L"
DETERMINES ITS SHAPE; "HYDRO3L" IS THE RESOURCE AMOUNT IN EJ;
"HYDRO4L" IS PRODUCTION PRICE IN 1975 DOLLARS PER GJ; AND
"HYDRO5L" IS THE ELECTRICITY SHARE OF HYDRO.

HYDROIL	HYDRO2L	HYDRO3L	HYDRO4L	HYDRO5L	REGION
42040	0.06505	1.83	4.33	0.15297	US
38610	0.07198	3.51	4.33	0.34268	NEUR+CAN
24160	0.06894	0.77	4.03	0.20997	JANZ
95788	0.09314	4.97	4.03	0.11581	EUSSR
20586	0.09008	3.76	4.03	0.34665	ACENP
64180	0.13488	3.61	4.03	0.09685	MIDEAST
37006	0.09969	7.31	4.03	0.28723	AFR
54322	0.07821	6.48	4.03	0.16237	LA
77222	0.10068	4.17	4.03	0.26934	SEASIA

GAS FLARING

"FLRL1" IS THE FLARING RATE IN 1975, "FLRL2" IS THE ULTIMATE
FLARING RATE, AND "FLRL3" IS THE NUMBER OF YEARS TO REACH "FLRL2"
THE MODEL EXPONENTIALLY INTERPOLATES BETWEEN THE RATES.

FLRL1	FLRL2	FLRL3	REGION
0.0550	0.0500	10.0000	US
0.0700	0.0500	10.0000	NEUR+CAN
0.0050	0.0100	10.0000	JANZ
0.0490	0.0500	10.0000	EUSSR
0.1070	0.0500	10.0000	ACENP
0.7270	0.0500	50.0000	MIDEAST
0.7360	0.0500	50.0000	AFR
0.5230	0.0500	28.0000	LA
0.3490	0.0500	15.0000	SEASIA

RENEWABLE RESOURCE CONSTRAINED TECHNOLOGIES

PARAMETERS INCLUDE LOGISTICS FUNCTION PARAMETERS, COST, AND SHARE
DATA. "HYDROIL" ORIENTS THE PRODUCTION PATH IN TIME; "HYDRO2L"
DETERMINES ITS SHAPE; "HYDRO3L" IS THE RESOURCE AMOUNT IN EJ;
"HYDRO4L" IS PRODUCTION PRICE IN 1975 DOLLARS PER GJ; AND
"HYDRO5L" IS THE ELECTRICITY SHARE OF HYDRO.

HYDROIL	HYDRO2L	HYDRO3L	HYDRO4L	HYDRO5L	REGION
0.4204	0.0650	1.8300	4.0300	0.1530	US
0.3861	0.0720	3.5100	4.0300	0.3427	NEUR+CAN
0.2416	0.0688	0.7700	4.0300	0.2100	JANZ
-1.9979	0.0931	4.9700	4.0300	0.1159	EUSSR
-3.2069	0.0908	3.7600	4.0300	0.3466	ACENP
-3.6418	0.1349	0.6100	4.0300	0.0969	MIDEAST
-3.9701	0.0997	7.3100	4.0300	0.2872	AFR
-2.5238	0.0978	6.4800	4.0300	0.1624	LA
-2.7723	0.1006	4.1700	4.0300	0.2693	SEASIA

Data Inputs: Supply Parameters (Continued)

Model Version A.84

Model Version B.82

PARAMETER VALUES FOR BACKSTOP SUPPLY TECHNOLOGIES
UNCONVENTIONAL OIL, UNCONVENTIONAL GAS, COAL, NUCLEAR, AND
ARE DESCRIBED SIMILARLY. EACH TECHNOLOGY HAS 9 DATA ELEMENTS
WHICH MUST BE READ IN FOR EACH REGION. THESE ARE: "CIL1"
THE BASE YEAR BREAKTHROUGH PRICE; "CIL2" — THE ULTIMATE
BREAKTHROUGH PRICE; AND "CIL3" — THE NUMBER OF YEARS TO REACH
"CIL2". "RIL" — SUPPLY PRICE ELASTICITY AT OIL AND GAS
QUANTITY; "BESILM" — BASE QUANTITY IN EACH PERIOD; "DILSET"
REFERENCE PRICE AT BASE QUANTITY, EXPRESSED AS A RATIO TO OIL
NOTE PRICES ARE 1975\$/GJ.

UNCONVENTIONAL OIL: I=1..L=1,2,...,9

CIL1	CIL2	CIL3	RIL	REGION
13.3100	7.3500	35.0000	1.1400	US
19.7000	7.3500	35.0000	1.1400	WEUR+CAN
13.3100	7.3500	35.0000	1.1400	JANZ
13.3100	7.3500	35.0000	1.1400	EUSSR
13.3100	7.3500	35.0000	1.1400	ACENP
13.3100	7.3500	35.0000	1.1400	MIDEAST
13.3100	7.3500	35.0000	1.1400	AFR
13.3100	7.3500	35.0000	1.1400	LA
13.3100	7.3500	35.0000	1.1400	SEASIA

UNCONVENTIONAL OIL: BESILM VALUES IN EJ

YEAR						DILSET
1975	2000	2025	2050	2075	2100	
1.00	3.57	15.80	41.16	77.13	130.35	1.3500
1.00	2.57	11.39	26.44	49.93	84.38	2.0000
1.00	1.13	5.02	11.75	22.02	37.21	1.3500
1.00	2.65	11.74	27.46	57.05	106.92	1.3500
1.00	0.28	1.80	15.09	31.34	58.74	1.3500
1.00	0.15	0.44	1.28	9.72	18.22	1.3500
1.00	0.15	1.00	8.37	19.26	40.01	1.3500
1.00	1.95	7.05	22.73	52.31	98.04	1.3500
1.00	0.15	1.00	6.37	17.39	32.59	1.3500

UNCONVENTIONAL GAS: I=1..L=1,2,...,9

CIL1	CIL2	CIL3	RIL	REGION
3.7000	3.7000	1.0000	0.4700	US
3.7000	3.7000	1.0000	0.4700	WEUR+CAN
3.7000	3.7000	1.0000	0.4700	OECD PAC
3.7000	3.7000	1.0000	0.4700	EUSSR
3.7000	3.7000	1.0000	0.4700	ACENP
3.7000	3.7000	1.0000	0.4700	MIDEAST
3.7000	3.7000	1.0000	0.4700	AFR
3.7000	3.7000	1.0000	0.4700	LA
3.7000	3.7000	1.0000	0.4700	SEASIA

UNCONVENTIONAL GAS: BESILM VALUES IN EJ

YEAR						DILSET
1975	2000	2025	2050	2075	2100	
15.00	15.00	15.00	15.00	15.00	15.00	1.7973
7.70	7.70	7.70	7.70	7.70	7.70	1.7973
0.0	1.10	1.10	1.10	1.10	1.10	1.7973
22.30	22.30	22.30	22.30	22.30	22.30	1.7973
2.85	2.85	2.85	2.85	2.85	2.85	1.7973
17.20	17.20	17.20	17.20	17.20	17.20	1.7973
5.60	5.60	5.60	5.60	5.60	5.60	1.7973
6.40	6.40	6.40	6.40	6.40	6.40	1.7973
2.60	2.60	2.60	2.60	2.60	2.60	1.7973

COAL: CIL1, CIL2, CIL3, RIL: I=1..L=1,2,...,9

CIL1	CIL2	CIL3	RIL	REGION
0.2600	0.2600	1.0000	0.2000	US
0.2600	0.2600	1.0000	0.2000	WEUR+CAN
0.2600	0.2600	1.0000	0.2000	OECD PAC
0.2600	0.2600	1.0000	0.2000	EUSSR
0.2600	0.2600	1.0000	0.2000	ACENP
0.2600	0.2600	1.0000	0.2000	MIDEAST
0.2600	0.2600	1.0000	0.2000	AFR
0.2600	0.2600	1.0000	0.2000	LA
0.2600	0.2600	1.0000	0.2000	SEASIA

COAL: BESILM VALUES IN EJ

YEAR						DILSET	RE
1975	2000	2025	2050	2075	2100		
17.18	32.00	51.14	88.23	152.24	273.14	1.9700	US
9.60	14.62	22.28	33.93	46.56	63.89	6.8100	WE
2.67	7.49	19.09	38.15	52.35	71.83	3.2700	JA
25.77	30.20	47.77	68.39	117.99	203.58	2.0000	EU
15.01	28.37	62.04	94.02	162.06	222.37	1.9700	AC
0.03	0.15	0.90	2.11	2.14	2.46	3.2700	MI
2.16	8.75	18.78	41.95	42.12	42.12	3.2700	AF
0.34	2.79	15.27	38.93	16.21	17.50	3.5400	LA
2.68	7.14	25.99	55.95	26.67	26.67	3.5400	SE

Data Inputs: Supply Parameters (Continued)

Model Version A.84

Model Version B.82

GLAR COSTS: CIL1 = PRODUCTION COST IN 1975
CIL2 = FINAL PRODUCTION COSTS
CIL3 = YEARS TO REACH FINAL PRODUCTION COSTS

CIL1	CIL2	CIL3	REGION
200.60	14.85	50.00	US
402.40	14.85	50.00	WEUR+CAN
281.60	14.85	50.00	OECD PAC
402.40	14.85	50.00	EUSSR
321.40	14.85	50.00	ACENP
128.60	14.85	50.00	MIDEAST
144.00	14.85	50.00	AFR
221.40	14.85	50.00	LA
200.60	14.85	50.00	SEASIA

NUCLEAR AND SOLAR COSTS: CIL1, CIL2, CIL3: L=1.....9

NUCLEAR			SOLAR			REGION
CIL1	CIL2	CIL3	CIL1	CIL2	CIL3	
6.83	14.85	50.00	200.60	14.85	50.00	US
6.83	14.85	50.00	402.40	14.85	50.00	WEUR+CAN
6.83	14.85	50.00	281.60	14.85	50.00	OECD PAC
6.83	14.85	50.00	402.40	14.85	50.00	EUSSR
25.80	14.85	50.00	321.40	14.85	50.00	ACENP
7.36	14.85	50.00	128.60	14.85	50.00	MIDEAST
25.80	14.85	50.00	144.00	14.85	50.00	AFR
7.36	14.85	50.00	321.40	14.85	50.00	LA
7.36	14.85	50.00	200.60	14.85	50.00	SEASIA

SYNFUEL PARAMETERS

(PARAMETERS INCLUDE A CONVERSION EFFICIENCY (GCI), ADD ON COSTS (HCILT) AND AN ELASTICITY CONTROL PARAMETER (RCI). HCILT1 IS THE INITIAL VALUE, HCILT2 THE FINAL VALUE, AND HCILT3 THE NUMBER OF YEARS TO REACH THE FINAL VALUE. THE MODEL EXPONENTIALLY INTERPOLATES FOR INTERMEDIATE YEARS)

SYNCRUDE			SYNGAS			REGION
HCILT1	HCILT2	HCILT3	HCILT1	HCILT2	HCILT3	
100.00	4.55	25.00	100.00	3.30	25.00	US
100.00	4.55	25.00	100.00	3.30	25.00	WEUR+CAN
100.00	4.55	25.00	100.00	3.30	25.00	OECD PAC
100.00	4.55	25.00	100.00	3.30	25.00	EUSSR
100.00	4.55	25.00	100.00	3.30	25.00	ACENP
100.00	4.55	25.00	100.00	3.30	25.00	MIDEAST
12.54	4.55	25.00	100.00	3.30	25.00	AFRICA
12.54	4.55	25.00	100.00	3.30	25.00	L AMER
100.00	4.55	25.00	100.00	3.30	25.00	SEE ASIA

SYNCRUDE GCI = 1.50
SYNCRUDE RCI = -6.00

SYNGAS GCI = 1.50
SYNGAS RCI = -6.00

SYNFUEL PARAMETERS

(PARAMETERS INCLUDE A CONVERSION EFFICIENCY (GCI), ADD ON COSTS (HCILT) AND AN ELASTICITY CONTROL PARAMETER (RCI). HCILT1 IS THE INITIAL VALUE, HCILT2 THE FINAL VALUE, AND HCILT3 THE NUMBER OF YEARS TO REACH THE FINAL VALUE. THE MODEL EXPONENTIALLY INTERPOLATES FOR INTERMEDIATE YEARS)

SYNCRUDE			SYNGAS			REGION
HCILT1	HCILT2	HCILT3	HCILT1	HCILT2	HCILT3	
100.00	4.55	25.00	100.00	3.30	25.00	US
100.00	4.55	25.00	100.00	3.30	25.00	WEUR+CAN
100.00	4.55	25.00	100.00	3.30	25.00	OECD PAC
100.00	4.55	25.00	100.00	3.30	25.00	EUSSR
100.00	4.55	25.00	100.00	3.30	25.00	ACENP
100.00	4.55	25.00	100.00	3.30	25.00	MIDEAST
12.54	4.55	25.00	100.00	3.30	25.00	AFRICA
12.54	4.55	25.00	100.00	3.30	25.00	L AMER
100.00	4.55	25.00	100.00	3.30	25.00	SEE ASIA

SYNCRUDE GCI = 1.50
SYNCRUDE RCI = -6.00

SYNGAS GCI = 1.50
SYNGAS RCI = -6.00

Demand Parameters. Very little was changed with regard to the demand side. The energy-service I-0 coefficients and the base service consumption weights are identical in both magnitude and format in both versions of the model.

The most major changes that were made center around the way price and income response parameters are entered. RPKK and RPK is entered as the secondary aggregate energy price elasticity of demand in Version A.84, while in Version B.82 the elasticity was defined in terms of aggregate energy services, not secondary energy. This change was made to accommodate the fact that most studies of price responsiveness refer to secondary energy while almost no studies refer to energy services directly. Since the values for RPKK and RPK in Version B.82 were derived from information on secondary energy price elasticities, this change relieves the user of the burden of translating the more common concept into terms that are unusual.

The model code was changed accordingly to facilitate this change in definition at the data input level. (See following discussion of changes in the demand module.)

The income elasticity for aggregate energy for non-OECD regions, RYKLT is entered as an initial value in 1975, which drops to .8 of its initial value for the USSR and .71 of its initial value for other regions, over a 75 year period. It is now entered as its actual value and not as one minus its actual value. See demand module changes.

Finally, the energy-GNP feedback elasticity, RY, was regionalized to become RYL.

Data Inputs: Demand Parameters

Model Version A.84

Model Version B.82

ENERGY SERVICE INPUT-OUTPUT COEFFICIENTS

TABLE 1.
ENERGY TRANSFORMATION BY SECTOR
(GJK, GJ)

OIL	GAS	COAL	ELECTRIC	SECTOR	VARIABLE
1.67	1.54	2.3	0.86	RES/COM	GJK,J=1,NJ
1.32	1.90	2.9	1.05	INDUSTRY	GJK,J=1,NJ
3.0	3.0	3.33	1.05	TRANSPORT	GJK,J=1,NJ
2.0	1.7	2.05	0.95	AGGREGATE	GJ, J=1,NJ

TABLE 2.
NON-ENERGY I-O COEFFICIENTS BY SECTOR
(HJK, MJ)

OIL	GAS	COAL	ELECTRIC	SECTOR	VARIABLE
4.93	3.24	2.37	3.41	RES/COM	HJK,J=1,NJ
.41	.32	.90	1.15	INDUSTRY	HJK,J=1,NJ
98.38	200.00	200.00	153.17	TRANSPORT	HJK,J=1,NJ
2.10	2.03	1.18	1.15	AGGREGATE	HJ, J=1,NJ

ENERGY SERVICE INPUT-OUTPUT COEFFICIENTS

TABLE 1.
ENERGY TRANSFORMATION BY SECTOR
(GJK, GJ)

OIL	GAS	COAL	ELECTRIC	SECTOR	VARIABLE
1.6700	1.5400	2.5000	0.2600	RES/COM	GJK,J=1,NJ
1.9200	1.9000	2.0000	1.0500	INDUSTRY	GJK,J=1,NJ
3.0000	3.0000	3.3300	1.0500	TRANSPORT	GJK,J=1,NJ
2.0000	1.7000	2.0500	0.9500	AGGREGATE	GJ, J=1,NJ

TABLE 2.
NON-ENERGY I-O COEFFICIENTS BY SECTOR
(HJK, MJ)

OIL	GAS	COAL	ELECTRIC	SECTOR	VARIABLE
4.9800	3.2400	2.8700	3.4100	RES/COM	HJK,J=1,NJ
0.4100	0.3200	0.8000	1.1600	INDUSTRY	HJK,J=1,NJ
98.8800	200.0000	200.0000	153.1700	TRANSPORT	HJK,J=1,NJ
2.1000	2.0300	1.1800	1.1500	AGGREGATE	HJ, J=1,NJ

BASE ENERGY SERVICE CONSUMPTION HEIGHTS
BY FUEL BY SECTOR BY REGION
SJKLP (UNITS=UNOIMENSIONED) AND BSKL (UNITS=EXAJOULES)

OIL	GAS	COAL	ELECTRIC	BSKL	SECTOR
0.185	0.593	0.011	0.379	15.2377	RES/COM
0.091	0.345	0.129	0.145	9.7881	INDUSTRY
1.369	0.000	0.000	0.001	6.6411	TRANSPORT
0.359	0.122	0.112	0.372	11.1476	RES/COM
0.260	0.365	0.131	0.212	9.4047	INDUSTRY
1.942	0.203	0.303	0.023	3.3974	TRANSPORT
0.443	0.088	0.207	0.462	2.0876	RES/COM
0.224	0.032	0.267	0.263	3.9391	INDUSTRY
2.672	0.000	0.001	0.050	0.8941	TRANSPORT
0.273	0.194	0.336	0.197	26.3832	AGGREGATE
0.196	0.005	0.754	0.074	9.1210	AGGREGATE
0.687	0.212	0.009	0.393	1.8153	AGGREGATE
0.437	0.009	0.340	0.214	2.2834	AGGREGATE
0.635	0.148	0.044	0.174	5.0434	AGGREGATE
0.515	0.368	0.172	0.244	4.2498	AGGREGATE

BASE ENERGY SERVICE CONSUMPTION HEIGHTS
BY FUEL BY SECTOR BY REGION
SJKLP (UNITS=UNOIMENSIONED) AND BSKL (UNITS=EXAJOULES)

OIL	GAS	COAL	ELECTRIC	BSKL	SECTOR	REGION
0.1850	0.5930	0.0110	0.3790	15.2377	RES/COM	USA
0.0910	0.3450	0.1290	0.1450	9.7881	INDUSTRY	USA
1.3690	0.0	0.0	0.0010	6.6411	TRANSPORT	USA
0.3590	0.1220	0.1120	0.3720	11.1476	RES/COM	WEUR+CAN
0.2600	0.0650	0.1310	0.2120	9.4047	INDUSTRY	WEUR+CAN
1.9420	0.0	0.0030	0.0280	3.3974	TRANSPORT	WEUR+CAN
0.4430	0.0880	0.2070	0.4620	2.0876	RES/COM	OECD PAC
0.2240	0.0320	0.2670	0.2630	3.9391	INDUSTRY	OECD PAC
2.6720	0.0	0.0010	0.0500	0.8941	TRANSPORT	OECD PAC
0.2730	0.1940	0.3360	0.1970	26.3832	AGGREGATE	USSR
0.1540	0.0050	0.7640	0.0740	9.1210	AGGREGATE	CHINA
0.6870	0.2120	0.0090	0.0930	1.8153	AGGREGATE	MIDEAST
0.4370	0.0090	0.3400	0.2140	2.2834	AGGREGATE	AFRICA
0.6350	0.1480	0.0440	0.1740	5.0434	AGGREGATE	L AMER
0.5160	0.0460	0.1720	0.2440	4.2498	AGGREGATE	SCE ASIA

BSJKLM -- LOGIT FUNCTION SCALE PARAMETERS
(UNITS BSJKLM=UNOIMENSIONED)

OIL	GAS	COAL	ELECTRIC	SECTOR	REGION
0.3535	0.0548	0.0008	0.5858	RES/COM	USA
0.1871	0.0124	0.0047	0.7958	INDUSTRY	USA
0.7030	0.0000	0.0004	0.2966	TRANSPORT	USA
0.5492	0.0814	0.0118	0.3577	RES/COM	WEUR+CAN
0.3184	0.0831	0.0122	0.5853	INDUSTRY	WEUR+CAN
0.0736	0.0030	0.5005	0.4256	TRANSPORT	WEUR+CAN
0.4533	0.3622	0.0058	0.4787	RES/COM	OECD PAC
0.1948	0.0420	0.0091	0.7541	INDUSTRY	OECD PAC
0.2293	0.0030	0.5779	0.3922	TRANSPORT	OECD PAC
0.4795	0.0380	0.0339	0.4486	AGGREGATE	USSR
0.5764	0.0018	0.1465	0.2753	AGGREGATE	CHINA
0.6032	0.0451	0.0025	0.3492	AGGREGATE	MIDEAST
0.7570	0.0004	0.0213	0.2113	AGGREGATE	AFRICA
0.7910	0.0186	0.0054	0.1850	AGGREGATE	L AMER
0.5503	0.0099	0.0260	0.4143	AGGREGATE	SCE ASIA

BSJKLM -- LOGIT FUNCTION SCALE PARAMETERS
(UNITS BSJKLM=UNOIMENSIONED)

OIL	GAS	COAL	ELECTRIC	SECTOR	REGION
0.3535	0.0548	0.0008	0.5858	RES/COM	USA
0.1871	0.0124	0.0047	0.7958	INDUSTRY	USA
0.7030	0.0	0.0004	0.2966	TRANSPORT	USA
0.5492	0.0814	0.0118	0.3577	RES/COM	WEUR+CAN
0.3184	0.0831	0.0122	0.5853	INDUSTRY	WEUR+CAN
0.0736	0.0	0.5008	0.4256	TRANSPORT	WEUR+CAN
0.4533	0.3622	0.0058	0.4787	RES/COM	OECD PAC
0.1948	0.0420	0.0091	0.7541	INDUSTRY	OECD PAC
0.0299	0.0	0.5779	0.3922	TRANSPORT	OECD PAC
0.4795	0.0380	0.0339	0.4486	AGGREGATE	USSR
0.5764	0.0018	0.1465	0.2753	AGGREGATE	CHINA
0.6032	0.0451	0.0025	0.3492	AGGREGATE	MIDEAST
0.7570	0.0004	0.0213	0.2113	AGGREGATE	AFRICA
0.7910	0.0186	0.0054	0.1850	AGGREGATE	L AMER
0.5508	0.0099	0.0260	0.4143	AGGREGATE	SCE ASIA

BSJKLM -- LOGIT FUNCTION SCALE PARAMETERS
(UNITS BSJKLM=UNOIMENSIONED)

OIL	GAS	COAL	ELECTRIC	SECTOR	REGION
0.2600	0.0548	0.0008	0.5858	RES/COM	USA
0.1871	0.0207	0.0047	0.7958	INDUSTRY	USA
0.7030	0.0000	0.0034	0.2966	TRANSPORT	USA
0.5492	0.0814	0.0118	0.3577	RES/COM	WEUR+CAN
0.3184	0.0831	0.0122	0.5853	INDUSTRY	WEUR+CAN
0.0736	0.0000	0.5005	0.4256	TRANSPORT	WEUR+CAN
0.4533	0.3622	0.0053	0.4787	RES/COM	OECD PAC
0.1948	0.0420	0.0091	0.7541	INDUSTRY	OECD PAC
0.5200	0.0200	0.1039	0.2753	AGGREGATE	USSR
0.6032	0.0451	0.0025	0.3492	AGGREGATE	CHINA
0.6700	0.0287	0.0213	0.2300	AGGREGATE	MIDEAST
0.6001	0.0423	0.0054	0.2117	AGGREGATE	AFRICA
0.6500	0.0187	0.0260	0.4400	AGGREGATE	SCE ASIA

BSJKLM -- LOGIT FUNCTION SCALE PARAMETERS
(UNITS BSJKLM=UNOIMENSIONED)

OIL	GAS	COAL	ELECTRIC	SECTOR	REGION
0.2600	0.0548	0.0008	0.5858	RES/COM	USA
0.1871	0.0207	0.0047	0.7958	INDUSTRY	USA
0.7030	0.0	0.0004	0.2966	TRANSPORT	USA
0.5492	0.0814	0.0118	0.3577	RES/COM	WEUR+CAN
0.3184	0.0831	0.0122	0.5853	INDUSTRY	WEUR+CAN
0.0736	0.0	0.5008	0.4256	TRANSPORT	WEUR+CAN
0.4533	0.3622	0.0058	0.4787	RES/COM	OECD PAC
0.1948	0.0420	0.0091	0.7541	INDUSTRY	OECD PAC
0.0299	0.0	0.5779	0.3922	TRANSPORT	OECD PAC
0.4795	0.0380	0.0339	0.4486	AGGREGATE	USSR
0.5200	0.0200	0.1039	0.2753	AGGREGATE	CHINA
0.6032	0.0451	0.0025	0.3492	AGGREGATE	MIDEAST
0.6700	0.0287	0.0213	0.2300	AGGREGATE	AFRICA
0.6001	0.0423	0.0054	0.2117	AGGREGATE	L AMER
0.6500	0.0187	0.0260	0.4400	AGGREGATE	SCE ASIA

Model Version B.82

BSJKLM -- LOGIT FUNCTION SCALE PARAMETERS
(UNITS BSJKLM=UNDIMENSIONED)

YEAR = 2000		ELECTRIC		SECTOR	REGION
OIL	GAS	COAL			
C.2600	C.0348	0.0008	0.5458	RES/COM	USA
C.1671	0.0327	0.0047	0.7958	INDUSTRY	USA
C.7030	0.0000	0.0000	0.0066	TRANSPORT	USA
C.5492	0.0814	0.0119	0.1577	RES/COM	WEUR+CAN
C.3184	0.0331	0.0122	0.5363	INDUSTRY	WEUR+CAN
C.0736	0.0000	0.5008	0.4256	TRANSPORT	WEUR+CAN
C.4533	0.0622	0.0053	0.4787	RES/COM	OCEC PAC
C.1948	0.0420	0.0091	0.7541	INDUSTRY	OCEC PAC
C.0299	0.0000	0.5773	0.3922	TRANSPORT	OCEC PAC
C.4735	0.1125	0.0198	0.4486	AGGREGATE	USSR
C.5764	0.0400	0.3706	0.2753	AGGREGATE	CHINA
C.6032	0.0451	0.0025	0.3492	AGGREGATE	MIDEAST
C.5800	0.0487	0.0213	0.3400	AGGREGATE	AFRICA
C.6001	0.0423	0.0034	0.2383	AGGREGATE	L AMER
C.4500	0.0273	0.0250	0.4500	AGGREGATE	SEE ASIA

OIL	GAS	COAL	ELECTRIC	SECTOR	REGION
0.2800	0.0548	0.0008	0.5858	RES/COM	USA
0.1871	0.0207	0.0047	0.7958	INDUSTRY	USA
0.7030	0.0	0.0004	0.2966	TRANSPORT	USA
0.5492	0.0814	0.0118	0.3577	RES/COM	WEUR
0.3184	0.0831	0.0122	0.5863	INDUSTRY	WEUR
0.0736	0.0	0.5008	0.4256	TRANSPORT	WEUR
0.4533	0.0622	0.0058	0.4787	RES/COM	OECO
0.1968	0.0429	0.0091	0.7541	INDUSTRY	OECO
0.0299	0.0	0.5779	0.3922	TRANSPORT	OECO
0.4795	0.1125	0.0198	0.4486	AGGREGATE	USSR
0.5764	0.0400	0.0706	0.2753	AGGREGATE	CHINA
0.6032	0.0451	0.0025	0.3492	AGGREGATE	MIDEA
0.5800	0.0487	0.0213	0.3400	AGGREGATE	AFRIC
0.6001	0.0423	0.0054	0.2383	AGGREGATE	L AME
0.4500	0.0273	0.0260	0.4500	AGGREGATE	SCE

BSJKLM -- LOGIT FUNCTION SCALE PARAMETERS
(UNITS BSJKLM=UNDIMENSIONED)

OIL		GAS		ELECTRIC		SECTOR	REGION
0.2600	0.0348	0.0008	0.5858	RES/COM	USA		
0.1871	0.0207	0.0047	0.7958	INDUSTRY	USA		
0.7030	0.0000	0.0704	0.2366	TRANSPORT	USA		
0.5492	0.0814	0.0118	0.3577	RES/COM	NEUR+CAN		
0.1184	0.0031	0.0122	0.5863	INDUSTRY	NEUR+CAN		
0.0736	0.0000	0.5038	0.4256	TRANSPORT	NEUR+CAN		
0.4533	0.0622	0.0058	0.4787	RES/COM	OECD PAC		
0.1948	0.0420	0.0091	0.7541	INDUSTRY	OECD PAC		
0.0299	0.0000	0.5779	0.3922	TRANSPORT	OECD PAC		
0.4743	0.1425	0.0128	0.4485	AGGREGATE	USSR		
0.4333	0.0300	0.0347	0.2753	AGGREGATE	CHINA		
0.6032	0.0451	0.0025	0.3492	AGGREGATE	MIDEAST		
0.4800	0.0787	0.0213	0.4000	AGGREGATE	AFRICA		
0.5001	0.0423	0.0054	0.2650	AGGREGATE	L AMER		
0.3900	0.0374	0.0260	0.4600	AGGREGATE	S&E ASIA		

OIL		GAS		COAL		ELECTRIC		SECTOR	REGION
0.2600	0.0548	0.0008	0.5858	RES/COM	USA				
0.1871	0.0207	0.0047	0.7958	INDUSTRY	USA				
0.7030	0.0	0.0004	0.2966	TRANSPORT	USA				
0.5492	0.0814	0.0118	0.3577	RES/COM	WEUR+				
0.3184	0.0831	0.0122	0.5863	INDUSTRY	WEUR+				
0.0736	0.0	0.5008	0.4256	TRANSPORT	WEUR+				
0.4533	0.0622	0.0058	0.4787	RES/COM	OCCD				
0.1948	0.0420	0.0091	0.7541	INDUSTRY	OCCD				
0.0299	0.0	0.5779	0.3922	TRANSPORT	OCCD				
0.4795	0.1425	0.0128	0.4486	AGGREGATE	USSR				
0.4323	0.0800	0.0347	0.2753	AGGREGATE	CHINA				
0.6032	0.0451	0.0025	0.3492	AGGREGATE	MIDEA				
0.4800	0.0787	0.0213	0.4008	AGGREGATE	AFRIC				
0.6001	0.0423	0.0054	0.2650	AGGREGATE	L A				
0.3900	0.0374	0.0260	0.4600	AGGREGATE	S E A				

BSJKLN — LOGIT FUNCTION SCALE PARAMETERS
(UNITS BSJKLN=UNDIMENSIONED)

YEAR = 2075		ELECTRIC		SECTOR	REGION
GIL	GAS	COAL		RES/COM	USA
C.2600	0.03548	0.0008	0.5358	INDUSTRY	USA
C.1871	0.0207	0.0047	0.7958	TRANSPORT	USA
C.7019	0.0030	0.0034	0.2966	RES/COM	NEUR+CAN
C.5432	0.0030	0.0113	0.3577	INDUSTRY	NEUR+CAN
C.3184	0.0031	0.0122	0.5883	TRANSPORT	NEUR+CAN
C.0736	0.0000	0.5008	0.4256	RES/COM	CEC/PAC
C.4533	0.0022	0.0758	0.4787	INDUSTRY	CEC/PAC
C.1343	0.0042	0.0091	0.7541	TRANSPORT	CEC/PAC
C.0299	0.0000	0.3779	0.3922	AGGREGATE	USSR
C.4735	0.1425	0.0118	0.4486	AGGREGATE	CHINA
C.4323	0.0000	0.2347	0.7513	AGGREGATE	MIDEAST
C.6032	0.0451	0.0025	0.3492	AGGREGATE	AFRICA
C.4866	0.0787	0.0213	0.4000	AGGREGATE	L AMER
C.6031	0.0423	0.0054	0.2530	AGGREGATE	SEE ASIA
C.3900	0.0374	0.0260	0.4606		

YEAR = 2075					
OIL	GAS	COAL	ELECTRIC	SECTOR	REGION
0.2600	0.0548	0.0008	0.58 58	RES/COM	USA
0.1871	0.0207	0.0047	0.79 58	INDUSTRY	USA
0.7030	0.0	0.0004	0.29 66	TRANSPRT	USA
0.5692	0.0814	0.0118	0.35 77	RES/COM	WEUR+
0.3184	0.0831	0.0122	0.58 63	INDUSTRY	WEUR+
0.0736	0.0	0.5008	0.42 56	TRANSPORT	WEUR+
0.4533	0.0622	0.0058	0.47 87	RES/COM	OECD
0.1948	0.0420	0.0091	0.75 61	INDUSTRY	OECD
0.0299	0.0	0.5779	0.39 22	TRANSPORT	OECD
0.4795	0.1425	0.0128	0.44 86	AGGREGATE	USSR
0.4323	0.0800	0.0347	0.27 53	AGGREGATE	CHINA
0.6032	0.0451	0.0025	0.34 92	AGGREGATE	MIDEAS
0.4800	0.0787	0.0213	0.40 00	AGGREGATE	AFRIC
0.6001	0.0423	0.0034	0.26 50	AGGREGATE	L AME
0.3900	0.0374	0.0260	0.46 00	AGGREGATE	SEE A

BSJKLM -- LOGIT FUNCTION SCALE PARAMETERS
(UNITS BSJKLM=UNDIMENSIONED)

YEAR = 2100		ELECTRIC		SECTOR	REGION
OIL	GAS	COAL		RES/COM	USA
C.2600	0.0548	0.0008	0.5958	INDUSTRY	USA
C.1371	0.0207	0.0047	0.7958	TRANSPORT	USA
C.7530	0.0500	0.0004	0.2966	RES/COM	NEUR+CAN
C.5492	0.0314	0.0118	0.3577	INDUSTRY	NEUR+CAN
C.3154	0.0931	0.0122	0.5863	TRANSPORT	NEUR+CAN
C.0736	0.0000	0.5008	0.4256	RES/COM	DECD PAC
C.4533	0.0622	0.0058	0.4787	INDUSTRY	DECD PAC
C.1948	0.0420	0.0091	0.7541	TRANSPORT	USSR
C.0299	0.0060	0.5779	0.3922	AGGREGATE	CHINA
C.4795	0.1425	0.0128	0.4486	AGGREGATE	MIDEAST
C.4333	0.0800	0.0347	3.2753	AGGREGATE	AFRICA
C.6032	0.0451	0.0023	0.3492	AGGREGATE	L AMER
C.4800	0.0797	0.0213	0.4006	AGGREGATE	SEE ASIA
C.6001	0.0423	0.0054	3.2650		
C.3900	0.0374	0.0260	3.4600		

		YEAR = 2100			
OIL	GAS	COAL	ELECTRIC	SECTOR	REGION
0.2600	0.0548	0.0008	0.5858	RES/CON	USA
0.1871	0.0207	0.0047	0.7958	INDUSTRY	USA
0.7030	0.0	0.0004	0.2946	TRANSPORT	USA
0.5642	0.0814	0.0118	0.3577	RES/CON	WEUR+
0.3184	0.0831	0.0122	0.5863	INDUSTRY	WEUR+
0.0734	0.0	0.5008	0.4256	TRANSPORT	WEUR+
0.4533	0.0622	0.0058	0.4787	RES/CON	OECD
0.1948	0.0420	0.0891	0.7541	INDUSTRY	OECD
0.0299	0.0	0.5779	0.3922	TRANSPORT	OECD
0.4795	0.1425	0.0128	0.4486	AGGREGATE	USSR
0.4323	0.0800	0.0347	0.2753	AGGREGATE	CHINA
0.6032	0.0451	0.0025	0.3492	AGGREGATE	MIDEAS
0.4800	0.0787	0.0213	0.4000	AGGREGATE	AFRICA
0.6001	0.0423	0.0054	0.2650	AGGREGATE	L AMER
0.3900	0.0374	0.0260	0.4608	AGGREGATE	SEE A

Model Version A.84

Model Version B.82

PRICE ELASTICITY CONTROL PARAMETERS

AGG	OIL	GAS	COAL	ELECTRIC	SECTOR
RPKK			RPJK		RES/CON
0.7	-3.0	-3.0	-3.0	-3.0	INDUSTRY
0.7	-3.0	-3.0	-3.0	-3.0	TRANSPORT
0.7	-13.0	-13.0	-13.0	-13.0	
RPK			RPJ		AGGREGATE
0.7	-2.5	-2.5	-2.5	-2.5	

AGG	OIL	GAS	COAL	ELECTRIC	SECTOR
RYKK			RYJK		RES/CON
1.00	-0.10	0.30	-0.20	0.10	INDUSTRY
1.000	0.00	0.10	-0.30	0.30	TRANSPORT
1.00	0.00	0.00	0.00	0.00	

0.10 0.10 -0.20 0.10 RYJ,J=1.4

LT--INCOME ELASTICITY FOR THE EUSSR (L=4) AND OTHER LDC'S (L INPUT IS THE INITIAL VALUE IN 1975. THE PROGRAM INTERPOLATES OVER A 75 YEAR PERIOD TO A FINAL VALUE 0.8 TIMES THE ORIGINAL FOR THE EUSSR AND 0.71 TIMES THE ORIGINAL FOR OTHER LDC'S

1.25 EUSSR(L=4)
1.40 LDC'S(L=4)

RYL--ENERGY-GNP FEEDBACK ELASTICITY, BY REGION

0.15	1=USA
0.15	2=NEUR+CAN
0.15	3=OECD PAC
0.15	4=EUSSR
0.20	5=ACENP
0.05	6=MIDEAST
0.20	7=AFRICA
0.20	8=L AMER
0.20	9=SEE ASIA

PRICE ELASTICITY CONTROL PARAMETERS

AGG	OIL	GAS	COAL	ELECTRIC	SECTOR
RPKK			RPJK		RES/CON
-1.3000	-3.0000	-3.0000	-3.0000	-3.0000	INDUSTRY
-0.9000	-3.0000	-3.0000	-3.0000	-3.0000	TRANSPORT
-5.5000	-13.0000	-13.0000	-13.0000	-13.0000	
RPK			RPJ		AGGREGATE
-1.0000	-2.5000	-2.5000	-2.5000	-2.5000	

AGG	OIL	GAS	COAL	ELECTRIC	SECTOR
RYKK			RYJK		RES/CON
1.0000	-0.1000	0.3000	-0.2000	0.1000	INDUSTRY
0.0	0.0	0.1000	-0.3000	0.3000	TRANSPORT
1.0000	0.0	0.0	0.0	0.0	

-0.1000 0.1000 -0.2000 0.1000 RYJ,J=1.4

INITIAL	FINAL	TIME	REGION
0.2500	0.0	75.0000	EUSSR(L=1)
0.4000	0.0	75.0000	LDC'S(L=2)

ENERGY-GNP FEEDBACK ELASTICITY

-0.1000 RY

CO₂ coefficients. The three data blocks of CO₂ coefficients, COI,

SBURUL/SHALE, and SFEDIL all enter in exactly the same way in both model versions.

Biomass. Biomass data inputs enter exactly as before in both model versions.

Changes in the demand module. Because several of the "housekeeping" adjustments that occur in the data base result in small changes in the demand module.

The first change encountered is the assignment of FK variables to calculate RYKT. Note that FK(1) no longer need have one added, that FK(2) is calculated in Version A.84 rather than assigned, and that FK(3) is set to 75 years automatically.

Model Version A.84

COI -- CARBON RELEASE BY SOURCE
(IN TERAGRAMS OF CARBON PER EXAJIOULE)

OIL BURNUP	GAS BURNUP	COAL BURNUP	COAL LIQ- UIFICATION	COAL GAS- IFICATION	SHALE OIL PRODUCTION
19.7	13.8	23.9	18.9	26.9	27.9

PROPORTION OF FLARED GAS BURNED (SBURNLT T=1 IS INITIAL
(1975) SHARE, T=2 IS ULTIMATE SHARE, T=3 IS NUMBER OF YEAR
TO SBURNLT. PROPORTION OF BACKSTOP FUEL FROM CARBONATE RO
(SHALET, T=1,2,3) HAS IDENTICAL INTERPRETATION.

SBURNLT	SBURNLT	SBURNLT	SHALET	SHALET	SHALET
0.13	0.13	1.00	0.01	0.99	70.00
0.47	0.15	25.00	0.01	0.45	70.00
1.00	0.15	35.00	0.01	0.99	70.00
1.00	0.15	35.00	0.01	0.99	70.00
1.00	0.15	35.00	0.01	0.99	70.00
0.90	0.15	35.00	0.01	0.25	70.00
0.90	0.15	35.00	0.01	0.25	70.00
0.90	0.15	35.00	0.01	0.25	70.00
0.35	0.15	25.00	0.01	0.25	70.00
0.85	0.15	35.00	0.01	0.25	70.00

FEEDSTOCK USES OF FOSSIL FUELS (SFEDIL) -- SHARE OF EACH
FOSSIL FUEL USED AS A FEEDSTOCK.

OIL	GAS	COAL	REGION
0.045	0.029	0.007	US
0.072	0.029	0.007	WEUR+CAN
0.092	0.029	0.007	OECD PAC
0.031	0.029	0.007	EUSSR
0.070	0.029	0.007	ACENP
0.141	0.029	0.007	MIDEAST
0.030	0.029	0.007	AFRICA
0.068	0.029	0.007	L AMER
0.082	0.029	0.007	SEE ASIA

BIOMASS COEFFICIENTS: THE SUPPLY FUNCTION FOR BIOMASS
INCLUDES WASTE AND "ENERGY FARMS" AS SEPARATE TECHNOLOGIES.
THE CODED FUNCTIONS ARE REPRESENTED BY LINEAR SEGMENTS.
THE JPARAMETERS ARE CRITICAL POINTS FOR THE FUNCTION AND
REGIONAL RESOURCES. BIOPSM ARE CRITICAL PRICE/SHARE
COMBINATIONS. BIOLM ARE MAXIMUM RESOURCE AMOUNTS -- WASTE
IS DEPENDENT ON ECONOMIC ACTIVITY. THE WASTE TOTAL IS
BASED ON 1975 ECONOMIC ACTIVITY (PRICE--1975 \$/GJ, QUANTITY--EJ)

WASTE (BIOPSM)	ENERGY FARMS (BIOPSM)	PRICE	SHARE	PRICE	SHARE
0.4000	0.1000	0.0	0.0		
1.6000	0.3000	2.1000	0.0		
4.6000	0.8000	2.6000	0.2000		
5.6000	0.8000	4.6000	0.8000		

WASTE (BIOLM)	ENERGY FARMS (BIOLM)	REGION
5.48	82.29	US
7.95	0.0	WEUR+CAN
2.71	13.19	OECD PAC
8.73	98.43	EUSSR
7.04	0.0	ACENP
1.00	0.0	MIDEAST
5.71	173.44	AFRICA
7.81	225.45	L AMER
10.40	0.0	SEE ASIA

INCOME ELASTICITY OF BIOMASS SUPPLY

0.5000 RYSMT

Model Version B.82

COI -- CARBON RELEASE BY SOURCE
(IN TERAGRAMS OF CARBON PER EXAJIOULE)

OIL BURNUP	GAS BURNUP	COAL BURNUP	COAL LIQ- UIFICATION	COAL GAS- IFICATION	SHALE OIL PRODUCTION
19.70	13.80	23.90	18.90	26.90	27.90

PROPORTION OF FLARED GAS BURNED (SBURNLT T=1 IS INITIAL
(1975) SHARE, T=2 IS ULTIMATE SHARE, T=3 IS NUMBER OF YEAR
TO SBURNLT. PROPORTION OF BACKSTOP FUEL FROM CARBONATE R
(SHALET, T=1,2,3) HAS IDENTICAL INTERPRETATION.

SBURNLT	SBURNLT	SBURNLT	SHALET	SHALET	SHALET
0.13	0.13	1.00	0.01	0.99	70.00
0.47	0.15	25.00	0.01	0.45	70.00
1.00	0.15	35.00	0.01	0.99	70.00
1.00	0.15	35.00	0.01	0.99	70.00
1.00	0.15	35.00	0.01	0.99	70.00
0.90	0.15	35.00	0.01	0.25	70.00
0.90	0.15	35.00	0.01	0.25	70.00
0.90	0.15	35.00	0.01	0.25	70.00
0.35	0.15	25.00	0.01	0.25	70.00
0.85	0.15	35.00	0.01	0.25	70.00

FEEDSTOCK USES OF FOSSIL FUELS (SFEDIL) -- SHARE OF EACH
FOSSIL FUEL USED AS A FEEDSTOCK.

OIL	GAS	COAL	REGION
0.0450	0.0290	0.0070	US
0.0720	0.0290	0.0070	WEUR+CAN
0.0920	0.0290	0.0070	OECD PAC
0.0910	0.0290	0.0070	EUSSR
0.0700	0.0290	0.0070	ACENP
0.1410	0.0290	0.0070	MIDEAST
0.0300	0.0290	0.0070	AFRICA
0.0680	0.0290	0.0070	L AMER
0.0820	0.0290	0.0070	SEE ASIA

BIOMASS COEFFICIENTS: THE SUPPLY FUNCTION FOR BIOMASS
INCLUDES WASTE AND "ENERGY FARMS" AS SEPARATE TECHNOLOGIES.
THE CODED FUNCTIONS ARE REPRESENTED BY LINEAR SEGMENTS.
THE JPARAMETERS ARE CRITICAL POINTS FOR THE FUNCTION AND
REGIONAL RESOURCES. BIOPSM ARE CRITICAL PRICE/SHARE
COMBINATIONS. BIOLM ARE MAXIMUM RESOURCE AMOUNTS -- WASTE
IS DEPENDENT ON ECONOMIC ACTIVITY. THE WASTE TOTAL IS
BASED ON 1975 ECONOMIC ACTIVITY (PRICE--1975 \$/GJ, QUANTITY--EJ)

WASTE (BIOPSM)	ENERGY FARMS (BIOPSM)	PRICE	SHARE	PRICE	SHARE
0.4000	0.1000	0.0	0.0		
1.6000	0.3000	2.1000	0.0		
4.6000	0.8000	2.6000	0.2000		
5.6000	0.8000	4.6000	0.8000		

WASTE (BIOLM)	ENERGY FARMS (BIOLM)	REGION
5.48	82.29	US
7.95	0.0	WEUR+CAN
2.71	13.19	OECD PAC
8.73	98.43	EUSSR
7.04	0.0	ACENP
1.00	0.0	MIDEAST
5.71	173.44	AFRICA
7.81	225.45	L AMER
10.40	0.0	SEE ASIA

INCOME ELASTICITY OF BIOMASS SUPPLY

0.3000 RYSMT

Demand Module Changes

Model Version A.84

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C
C -----
C INTERPOLATE INCOME ELASTICITY VALUES
C -----
C
NT=(M-1)*NJUMP
T=NT
IT=NJUMP
DO 45 IT=1,2
  FK(1)=RYKLT(1)
  IF (IT.EQ.1) FK(2)=RYKLT(1)+0.8000
  IF (IT.EQ.2) FK(2)=RYKLT(1)+0.7100
  FK(3)=75.00
  NYK(1)=XINTERP(FK(1),FK(2),FK(3),T)+1.00
45 CONTINUE

C
DO 150 L=1,NL
  NK=NKL(L)
  X=VLMIL,M)/ZLMIL,M)/ZLMIL,1)
C -----
C CALCULATE FK, THE DEMAND FOR ENERGY SERVICES BY SECTOR K
C -----
DO 30 K=1,NK
  IF (NK-1) 10,10,20
10 CONTINUE
  IFIL=EQ. 4) RYK=RYK(1)
  IFIL=NE. 4) RYK=RYK(2)
  FK(K)=BSKLIK,L)*PKLM(K,L,M)*RPKLIK,L)*X+RYK*VLMIL,M)
  GO TO 30
20 FK(K)=BSKLIK,L)*PKLM(K,L,M)*RPKLIK,L)*X+RYK*VLMIL,M)
  IFIL=EQ. 2) FK(K)=BSKLIK,L)*PKLM(K,L,M)*RPKLIK,L)
  IFIL=EQ. 2) FK(K)=FK(K)+VLMIL,M)*RYK(K)
30 CONTINUE

C
C COMPUTE NUMERATOR AND DENOMINATOR OF SJKL.
C USE SJKL AS TEMPORARY NUMERATOR.
C
DO 90 K=1,NK
  SUM=0.00
  DO 70 J=1,NJ
    IF (NK-1) 40,40,50
    SJKL(J,K,L)=BSJKLM(J,K,L,M)*PJKLM(J,K,L,M)*RPJ(J)*X+RYJ(J)
    GO TO 60
50 SJKL(J,K,L)=BSJKLM(J,K,L,M)*PJKLM(J,K,L,M)*RPJ(K)
    X=RYJ(K)
60 SUM=SUM+SJKL(J,K,L)
70 CONTINUE
  DO 80 J=1,NJ
    SJKL(J,K,L)=SJKL(J,K,L)/SUM
80 CONTINUE
90 CONTINUE

C
C COMPUTE TOTAL FUEL DEMANDS
C
DO 140 J=1,NJ
  FJL(J,L)=0.00
  DO 130 K=1,NK
    TECH=1.00+FK(K,L)*T
    FJL(J,K,L)=SJKL(J,K,L)*FK(K)/TECH
    IF (NK-1) 100,100,110
    FJL(J,K,L)=FJL(J,K,L)+GJL(J)
    GO TO 120
110 FJL(J,K,L)=FJL(J,K,L)+GJL(J,K)
120 FJL(J,L)=FJL(J,L)+FJL(J,K,L)
130 CONTINUE
140 CONTINUE

C
150 CONTINUE

C
DO 230 L=1,NL
  NK=NKL(L)
  NKK=NKK(L)
  IF (NKK.EQ. 1) GO TO 151

```

Model Version B.82

```

C
C -----
C INTERPOLATE INCOME ELASTICITY VALUES
C -----
C
NT=(M-1)*NJUMP
T=NT
DO 42 IT=1,2
  FK(1)=RYKLT(1)+1.00
  FK(2)=RYKLT(1)+1.00
  FK(3)=RYKLT(1)+1.00
  NYK(1)=XINTERP(FK(1),FK(2),FK(3),T)+1.00
42 CONTINUE

C
DO 150 L=1,NL
  NK=NKL(L)
  X=VLMIL,M)/ZLMIL,M)
C -----
C CALCULATE FK, THE DEMAND FOR ENERGY SERVICES BY SECTOR K
C -----
DO 30 K=1,NK
  IF (NK-1) 10,10,20
10 CONTINUE
  IFIL=EQ. 4) RYK=RYK(1)
  IFIL=NE. 4) RYK=RYK(2)
  FK(K)=BSKLIK,L)*PKLM(K,L,M)*RPK(K)*X+RYK*VLMIL,M)
  GO TO 30
20 FK(K)=BSKLIK,L)*PKLM(K,L,M)*RPK(K)*X+RYK*VLMIL,M)
  IFIL=EQ. 2) FK(K)=FK(K)
30 CONTINUE

C
C COMPUTE NUMERATOR AND DENOMINATOR OF SJKL.
C USE SJKL AS TEMPORARY NUMERATOR.
C
DO 90 K=1,NK
  SUM=0.00
  DO 70 J=1,NJ
    IF (NK-1) 40,40,50
    SJKL(J,K,L)=BSJKLM(J,K,L,M)*PJKLM(J,K,L,M)*RPJ(J)*X+RYJ(J)
    GO TO 60
50 SJKL(J,K,L)=BSJKLM(J,K,L,M)*PJKLM(J,K,L,M)*RPJ(K)
    X=RYJ(K)
60 SUM=SUM+SJKL(J,K,L)
70 CONTINUE
  DO 80 J=1,NJ
    SJKL(J,K,L)=SJKL(J,K,L)/SUM
80 CONTINUE
90 CONTINUE

C
C COMPUTE TOTAL FUEL DEMANDS
C
DO 140 J=1,NJ
  FJL(J,L)=0.00
  DO 130 K=1,NK
    (FJL(J,K,L)=SJKL(J,K,L)*FK(K)/FJL(J,K,L,P))
    IF (NK-1) 100,100,110
    FJL(J,K,L)=FJL(J,K,L)+GJL(J)
    GO TO 120
110 FJL(J,K,L)=FJL(J,K,L)+GJL(J,K)
120 FJL(J,L)=FJL(J,L)+FJL(J,K,L)
130 CONTINUE
140 CONTINUE

C
150 CONTINUE

C
DO 230 L=1,NL
  NK=NKL(L)
  NKK=NKK(L)
  IF (NKK.EQ. 1) GO TO 151

```

The next change deals with the way in which X, the per capita income index, is calculated. Because population is entered in natural units in Version A.84 rather than an index as in Version B.82, the index must be created in the equation itself.

The most subtle looking change turns out, in fact, to be one of the more complicated. In Version A.84 the variable RPKL replaces RPK. Because RPK, the old energy service price elasticity became the secondary energy service price elasticity, a transformation became necessary.

The relationship between a secondary energy price elasticity, r, and the derived energy service price elasticity r^* is given by

$$r^* = r \left(\sum_j S_{jkl} (P_{jlm} g_j^{th}) \right) / \left(\sum_j S_{jkl} P_{jlm} g_j \right)$$

In the model code r^* is designated as RPKL, while r becomes the old RPK. Note that because the secondary energy price elasticity r is assumed fixed that r^* must be sector and region specific. The mapping from RPK to RPKL is conducted in subroutine RSPS as energy service prices are calculated. The code follows with changes circled:

```

C
C
C COMPUTE THE ENERGY SERVICE PRICES
C
      PS=0.00
      DO 110 K=1,NK
        PKLM(K,L,M)=0.00
        RPKL(K,L)=0.00
        DO 100 J=1,NJ
          IF (NK.EQ.1) PP=PJLM(J,L,M)*GJ(J)+HJ(J)
          IF (NK.NE.1) PP=PJLM(J,L,M)*GJK(J,K)+HJK(J,K)
          PJKLM(J,K,L,M)=PP
          PKLM(K,L,M)=PKLM(K,L,M)+SJKLP(J,K,L)*PJKLM(J,K,L,M)
          IF (NK.EQ.1) PP=PP-HJ(J)
          IF (NK.NE.1) PP=PP-HJK(J,K)
          RPKL(K,L)=RPKL(K,L)+PP*SJKLP(J,K,L)
100      CONTINUE
      PS=PS+SJKL(K,L)*PKLM(K,L,M)
      IF (NK.EQ.1) RPKL(K,L)=RPK*PKLM(K,L,M)/RPKL(K,L)
      IF (NK.NE.1) RPKL(K,L)=RPK*PKLM(K,L,M)/RPKL(K,L)
110 CONTINUE
      IF (M.EQ.1) BPSL(L)=PS
      PS=PS/BPSL(L)

```

The next block of changes, while apparently larger are in fact really very minor. The number 20 statement is broken up into two lines to accommodate the longer RPKL which replaced RPKK in Version A.84. The following "IF" statement is now written out rather than dealt with indirectly.

Finally, the variable TECH is created to replace TJKLM. The exogenous energy efficiency is now calculated in the preceding line from, TKL, the rate of improvement.