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ROLE OF THE BREEDER IN LONG-TERM ENERGY ECONOMICS

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ABSTRACT

In this study we report the results of our study of private and public decisions affecting the use of nuclear and other energy technologies over a long-run time horizon. For this purpose, we employ the well known ETA-MACRO model which provides for economic- and energy-sector interactions. In this first of our planned series of studies, we consider the impact on the use of competing energy technologies of a public decision to apply benefit-cost analysis to the production of carbon dioxide (CO_2) that enters the atmosphere.

Assuming the public choice is to impose an appropriate penalty tax on those technologies which generate CO_2 and to allow decentralized private decisions to choose the optimal mix of energy technologies that maximize a nonlinear objective function subject to constraints, we find that the breeder technology is chosen to provide a much-larger share of domestically consumed energy. Having the breeder technology available as a substitute permits control of CO_2 without significant reductions in consumption or gross national product growth paths.

INTRODUCTION

We are interested in those private and public decisions that will determine the energy technology mix in use in the very long run. We do not consider transitory shortages or gluts of energy resources such as crude oil. With that horizon in mind, our focus is on trends in demand, economic exhaustion paths of finite energy resources, capital and other costs for particular technologies, and public policy decisions affecting energy use such as environmental quality control choices. In this first of a series of studies, we modify the well known ETA-MACRO long run model to investigate the impact on the long run energy technology mix of a public effort to limit carbon dioxide (CO_2) in the atmosphere by means of a penalty tax on energy technologies emitting that pollutant.

Our perferred interpretation of our results is that they not be regarded as forecasts or predictions of the long run future, but as quantitative estimates of the consequences of private and public decisions as embodied in an economic-energy sector model that we shall specify shortly. For example, in our base case we present the time profiles (through 2050) of economic and energy technology variables that are the outcomes of decisions leading to a relatively high economic growth path. Such a growth path generates levels of CO_2 in the atmosphere that could affect the dynamic and stochastic nature of the climate so as to produce temperature, precipitation and other weather manifestations that are significantly different from those found in regions of the planet today. If these changes are not desired, then various control mechanisms may be chosen including an appropriate penalty tax on fossil fuels. We impose such a tax in our model and generate another set of time profiles or an alternate growth path that reveals a substitution of alternate energy technologies for those using fossil fuels. The analysis depends, of course, upon substitution possibilities in the model and upon the availability and properties of alternative energy options. Among the options we specify in the model, we find the fast breeder technology becomes one of the lowest cost energy resources that to a large extent replaces fossil fuels, and permits the attainment of continued positive (real) growth paths for consumption and gross national product. It is the comparison of growth paths (or differences in particular time profiles) that matters in our approach.

THE ENERGY-ECONOMY MODEL: ETA-MACRO

After a review of existing long run models, we selected ETA-MACRO, developed by Alan Manne, because it permitted plausible energy sector-macroeconomy interdependencies, was clearly specified, and enabled the user to make modifications in a number of important respects (1). Other models had these and other desirable features in large degree also, but the frequent use of ETA-MACRO has resulted in its properties being relatively well understood. It is a highly aggregated model and in future work we plan to test the robustness of some of our results by making similar use of models more disaggregated, for example, on the energy demand side. Since ETA-MACRO has been documented elsewhere, we shall discuss only those aspects of the model which are relevant to our purposes.

ETA-MACRO is a set of macroeconomic and energy sector relationships or equations so formulated over time that they may be solved by nonlinear programming methods to give at five year intervals solution values to the unknowns (and their duals) that maximize (minimize) a specified objective function. This formulation has a number of attractive features: it may be considered a simulation of private decisions in the market place that aim to maximize profits or utility, and a simulation of public policy decisions that aim to achieve a public purpose at minimum cost. We write the criterion or objective function as

$$\text{Max } W_t = AC_t^{\delta_0} C_{t+1}^{\delta_1} \cdots C_{t+\theta}^{\delta_\theta} \qquad [1]$$

where the goal is to maximize well-being W as the product over time of aggregate consumption expenditures, C. Exponents δ_i are to be interpreted as discounts or $\delta_i = 1/(1+\delta)^i$ where δ is the one period utility discount rate (= 0.1 in our study). Our long run comprises 14 five year intervals after which a steady state path of consumption grows at a rate g. Marginal utility ($\partial W_t / \partial C_t = \delta_0 W_t / C_t$) is always positive, and diminishing, enabling us to conclude that any growth path with at least one C greater than, and no others less than, corresponding elements of another growth path will yield greater well-being as compared with its competitor. Note that the solution to [1] requires a simultaneous consideration of values of C at all t. By definition

$$Y_t = C_t + I_t + EC_t, \qquad [2]$$

that is, consumption will be maximized when gross output Y is maximized while I, investment in nonenergy capital, and EC, energy costs, are minimized. Gross national product, GNP = Y − EC.

A two stage production function is an essential structural relationship of this model. It may be written as a nested four input relation

$$Y_t = \left[a\left(K_t^{\alpha} L_t^{1-\alpha}\right)^{\rho} + b\left(E_t^{\beta} N_t^{1-\beta}\right)^{\rho}\right]^{1/\rho} \qquad [3]$$

where K, L, E, and N, are nonenergy capital, labor, electrical energy and nonelectrical energy flows. Parameters a and b are positive, and termed distribution parameters. Parameters α and β (= 0.33) permit first stage substitutions given input price changes so that, for example, the optimal energy technology mix is first selected. The parameter ρ permits a second stage substitution between the capital-labor combination and the energy mix. This second stage decision is determined by the elasticity of substitution (ESUB) which is defined as the percent reduction in total demand for energy associated with a one percent increase in the price of energy relative to that of capital and labor. As all price-induced substitutions are made on the supply side through the production function, specifications [2] and [3] provide three links between the macroeconomy and the energy sector in that the indirect demands for inputs E and N arise from the production process subject to the requirement that total energy cost (EC) be minimized. In turn rising energy prices, for example, can slow the growth rate of Y (and GNP) below its potential.

The energy sector comprises a set of selected technologies together with associated costs and material (e.g., nuclear fuel cycle) requirements, a vector of energy resource reserves with associated supply prices, and a list of capacity and other constraints embodying judgments on initial capacities and capacity growth capabilities. It is difficult in a short space to write these numerous, and important, inequalities. It may suffice to do two things. First, to note that if the energy technologies selected are considered column headings and each row is considered the consumption of a particular energy resource by the technologies, then the resultant matrix of equations may be considered a system of inequalities given limited reserves that cannot be violated in maximizing the nonlinear objective function. Additional constraints are required for nonnegativity and capacity requirements. Second, to provide the reader with details on the numerical values that were used in the specification of this matrix, we have summarized in Table 1 essential cost and materials flow data.

It will be noted that of the thirteen energy technologies listed in Table 1 that are permitted to compete in our study, seven directly produce electricity. Substitution occurs among all energy technologies as electrical energy can be substituted (recall the production function first step decision process) for nonelectrical (in heating, for example).

The economic exhaustion of finite energy resources plays an important role in long run studies such as ours. Disagreement continues on the amounts of proven stocks not to mention unproven. We have followed the amounts and supply prices provided by the builders of ETA-MACRO as they appear to avoid optimistic or pessimistic extremes (Table 2). Over the long run, use of finite resources results in exponentially rising real royalties or net prices and becomes an important driving force leading to substitution among energy technologies. In our study, the penalty tax we impose on offending (CO_2) energy technologies dominates the many issues involved in estimating resources.

Energy demand is derived from the growth of output via the production function although higher energy prices can cause the economy to fail to achieve its potential growth because other inputs must be substituted for energy. The labor force growth rate as augmented by technological progress is a major determinant of the economy's potential growth path. This potential U.S. growth path is exogenously determined in the model. At a moment in history when our confidence in long run growth rates may have been jolted by the events of the 1970s, it takes something of an act of confidence in the future to assume annual rates of potential growth of 3.5 percent in the period 1980 to 1990 declining to 2 percent in the period 2010 to 2050. At the same time these rates of growth are far below those of the 1950s and 1960s. We adopt the estimates of positive growth rates starting at 3.5 and declining to 2 percent in real terms without apology or rationalization. We consider it interesting and important to explore the consequences of using this growth path as a base case in our study.

Table 1. U.S. Energy Sector Technology Cost and Material Flow Data

	1980 Costs		
	Annual Levelized[a]	Electric Investment	Nonelectric Investment
Electric Technologies	mills/kWh	$/kW	$/kW
Hydroelectric, geothermal (HYDRO)	27.66	1520	0
Coal fired (COLC)	20.74	1250	176
Nuclear-LWR (LWRA)	28.73	1423	80
Nuclear-breeder (FBRX)	34.74	1674	147
Remaining initial fossil (PGEL)	3.06	0	0
Surface coal (RCOL)	3.47	0	0
Solar, fusion (ADVX)	57.29	3530	0
Nonelectric Technologies	$/MBTU	$/kW	$/MBTU
Petroleum and natural gas (PETG)	0	0	0
Oil imports (PGIM)	2.94	0	0
Coal based synthetic (SYNF)	4.09	0	0
Shale oil (SHAL)	6.50	0	20.0
Coal for direct use (CLDU)	1.40	0	0
Nonelectric alternate energy (NAES)	11.20	0	33.7

[a] Excludes resource cost.

Transmission and distribution costs (electrical technologies) = 8.17 mills/kWh.

Nuclear Technologies

Mass Flow and Enrichment Requirements for Fuel Cycle

	NATU ST/GW	PLUT MT/GW	SWU MT/GW	NATU ST/GW-yr	PLUT MT/GW-yr	SWU MT/GW-yr
LWRA	439	0	224	169	-0.18	102
FBRX	0	5	0	0	-0.20	0

Assume 65% capacity factor; ST = short tons; MT = metric ton.

Data source: Reference (2).

Table 2. U.S. Energy Resources: Quantity vs. Price Schedule

Level	Petroleum and Natural Gas		Coal		Natural Uranium	
	Cumulative (quads)	$/MBTU	Cumulative (quads)	$/MBTU	Cumulative (MST)	$/lb
1	1000	2.94	250	1.72	1.5	30.00
2	1200	3.60	1000	2.13	2.9	71.00
3	1343	4.10	1750	2.42	3.9	125.50
4	1450	4.70	2500	2.77	4.5	158.00
5	1535	5.30	3250	3.11	8.0	354.00
6	1600	5.90	10000	3.27	100.0	3000.00
7	1800	20.00				
8	10000	50.00				

Note: The supply price is for the incremental energy consumed as one moves from level to level; e.g., in the case of petroleum and natural gas 200 quads are consumed from level 1 to level 2 at a price $3.60/MBTU. MBTU = million British thermal units. MST = million short tons.

Data Source: Reference (2).

One immediate consequence of this growth path may be deduced from the (linear homogeneous) production function. Expansion of demand with unchanged input prices implies an unitary income elasticity of demand for energy inputs.

BASE CASE RESULTS

The nonlinear programming solution, if one exists, provides a vector of consumption amounts in five year intervals over the long run horizon that maximizes the welfare criterion. Any intertemporal reallocation in these values would lead to a lower social utility or welfare. Also provided simultaneously are vectors over time of GNP, investment and energy costs. The latter is minimized by that choice of energy technologies which is least cost in the light of price, resource capacity, or other constraints. Note these constraints yield in our study not one but a mix of energy technologies.

In Table 3 we present in row section 1 a breakdown of the competing energy resources (and technologies) as they are utilized over time. We have provided annual flow data in quads at ten year intervals. Fossil fuels provide over 90 percent of domestic energy production in 1980. While this share declines to a little over 70 percent in the year 2050, it remains the major energy resource in use. In the case of electricity generation, row section 4, the base case run reveals a time profile of initial heavy dependence on coal. This dependence declines as nuclear plants are brought on stream, but again takes on a dominant role in this market as uranium prices rise. The latter rise is not sufficient in the base run to make the breeder competitive nor is the plutonium constraint on the breeder relaxed given the light water reactor generation levels.

The macroeconomic results in row section 6 show that the economy has achieved, in this base run, impressive levels of GNP, C, and I over time. The GNP level of 12 trillion dollars (deflated) in 2050 provides a per capita income that should enable society, if the base run should in fact materialize, to resolve many of its scarcity problems including poverty. At the same time certain problems of a high income economy are likely to be accentuated; for example, the problem of maintenance of environmental quality, and specifically, the problem of CO_2 control. We have calculated in row section 7 the cumulative carbon content of the base run growth path that reveals a dumping of 244 billions of tons of carbon into the global environment. We turn to a consideration of this problem.

CARBON DIOXIDE ENVIRONMENTAL QUALITY AND DAMAGE FUNCTIONS

The ETA-MACRO model in our base run simulated a private enterprise economy over time in which decentralized decisions were made about the allocation of income (output) between consumption and investment, and about the allocation of production expenditures (costs) among inputs, including energy technologies. Government policies were assumed to be unchanged over time, and, in fact, the implicit assumption was made that government control of energy prices was completely relaxed. The calculation of private benefits and costs guided market decisions.

Market externalities are those benefits and costs which transcend private accounting. The classic example is smoke from the factory's chimney that affects climate and human health at an extra real cost to the consumer not to the producer. Public intervention in the private market system may be justified in these cases, although it must be noted that private negotiations about external benefits and costs is possible in some cases, and it must also be noted that measurement of external benefits and costs is often difficult. The production of CO_2 by an energy technology is a good example of a market externality that probably cannot be handled by private negotiations and will require for its control, if that is the public decision, policy intervention. Our fundamental question then takes on two aspects: what measures of control are available, and what are the optimal levels of control systems? Answers to these questions will enable us to generate another comparative run of ETA-MACRO incorporating an optimal level of the CO_2 control system.

Although controvesy surrounding the carbon dioxide problem has been reduced as new research clarifies its nature, it remains true that there are a number of unresolved issues concerning both the generation and distribution of carbon, and the effect of levels of carbon in various strata upon climate. These issues are the subjects of continuing research that is likely to provide a relatively sound base for public policy in the not too distant future; that is the reason for our choosing this problem for our run. However, we are not arguing for a new priority to be assigned this matter, nor are we urging a particular course of action for the public sector. We are asking a different question: if one is interested in this problem area and if one is interested in the consequences of a particular policy choice to control CO_2, then can we provide a simulation of the economy incorporating this policy change? A comparison of this policy-affected run with our base case run could provide quantitative measures of the consequences of this course of action for key variables.

In discussions of market externalities that affect the environment, it is useful first to define an environmental quality function (EQF). Briefly expressed, this function, if known, assigns to each pollution generation source, a set of coefficients that reveal how various activity levels of that source produce or emit the material or substance in question that get into the various areas or strata of the environment. A matrix of these coefficients with each column indicating an environmental region (such as the biosphere or troposphere) could be premultiplied by a vector of source activity levels to yield per unit of time the increase in the pollutant concentrations. Net

Table 3

BASE DATA RUN (1980 BASE YEAR WITHOUT LOAD-DURATION CONSTAINTS)
(ESUB = 0.333)

	1980	1990	2000	2010	2020	2030	2040	2050
1. Domestic Energy Production (Quads)	61.41	76.36	102.28	125.04	154.58	201.86	255.72	333.42
1.1. Coal, Total:	15.40	23.13	33.85	50.93	70.42	99.04	145.68	230.81
A. For Electricity Generation	11.31	15.92	20.88	31.98	41.04	51.42	79.65	146.38
B. For Synthetic Fuels	0.0	0.75	3.75	7.50	15.00	30.00	45.00	60.00
C. Direct Use and Other	4.09	6.46	9.22	11.45	14.36	17.62	21.02	24.43
1.2. Petroleum and Gas	40.01	40.00	40.00	31.47	24.37	18.82	14.52	11.20
1.3. Nuclear Electricity, Total	3.00	8.67	20.24	30.00	41.82	57.18	56.94	38.46
A. LWR	3.00	8.67	20.24	30.00	40.00	39.94	29.18	12.51
B. FBR	0.0	0.0	0.0	0.0	1.82	17.24	27.76	25.94
C. Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.4. Advanced Electric	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.5. Shale-Oil, Tar Sands, Etc.	0.0	0.50	2.50	5.00	7.00	9.00	11.00	12.00
1.6. Hydro., Geothermal, Etc.	3.00	4.06	5.69	7.65	10.28	13.82	16.57	24.95
1.7. Unconventional Nonelectric	0.0	0.0	0.0	0.0	0.70	4.00	9.00	16.00
2. Petroleum and Gas Imports (Quads)	14.50	12.51	9.05	13.83	14.31	4.40	0.0	0.0
3. Total Energy Consumption (Quads)	75.91	88.87	111.33	138.88	168.89	206.26	255.72	333.42
4. Electricity Generation (Trillion KWH)	2.37	3.36	4.97	7.05	9.42	12.38	15.73	21.37
4.1. % Hydro., Geothermal, Etc.	12.66	12.07	11.45	10.85	10.91	11.16	11.81	11.68
4.2. % Fossil Electric	74.68	62.15	47.82	46.53	44.71	42.65	51.99	70.33
4.3. % Nuclear	12.66	25.78	40.73	42.56	44.38	46.19	36.20	18.00
4.4. % Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5. Resource Requirements, Cumulative From 1980								
Petroleum and Gas (Quads)	200.05	600.05	1000.05	1339.09	1600.00	1801.22	1956.48	2076.27
Coal (Quads)	76.99	277.53	585.46	1052.25	1711.29	2612.01	3928.38	8604.43
Natural Uranium (Million Short Tons)	0.0774	0.3648	0.8956	1.6954	2.7402	3.7564	4.5000	4.8032
6. GNP (Trillions of 1980 Dollars)	2.626	3.549	4.871	6.314	7.785	9.212	10.996	12.104
Consumption	2.310	3.010	4.154	5.464	6.773	7.947	9.367	10.541
Investment	0.316	0.538	0.717	0.851	1.012	1.266	1.628	1.563
Energy Costs	0.225	0.320	0.426	0.654	0.899	1.304	1.930	3.956
7. Environmental Quality Cumulative Carbon Content (Billions of Tons)								
Fossile Fuel Total	8.66	26.99	47.98	73.16	102.85	136.53	179.50	243.71

pollutant additions require more information about dispersion and movements from strata to strata.

It is reported that about 98 percent of industrial carbon dioxide generation originates in the energy sector (3). For our purposes we utilize a simple linear quality function in which two categories of fossil fuels generate carbon that makes up the major dimension of the problem in an aggregated region called the atmosphere (see Table 4, CO_2 EQF).

The environmental damage function, if known, assigns to pollutant concentrations in particular strata those health, esthetic, or other consequences that may be used as a foundation for cost or damage estimates. A doubling of present CO_2 concentrations in the atmosphere, for example, is estimated to change surface temperatures at various latitudes to a significant extent (3). By "significant" we mean that such important variables in the stochastic climate system as the floating ice pack will be affected. Precipitation, regional temperature variations, and other weather manifestations of climate will alter the production functions in agriculture and other sectors with important economic consequences. Adoption of a limit to global CO_2 concentration would seem to be an interesting issue for policy consideration (5).

RESULTS OF THE POLICY AFFECTED RUN

CO_2 concentration in the atmosphere is a global problem, but our focus in this paper is on private and public decisions within the U.S. We may relate U.S. activity to the larger scene by defining the U.S. share of the "global sink" into which CO_2 may be dumped. In 1974 an estimate of 702 billion tons of carbon by weight is available for the existing concentration level (6). We have adopted, therefore, an upper limit of 1,400 billion tons of carbon by weight for the global atmospheric system. U.S. energy consumption may be estimated to have been about 33 percent of the global total in the 1970s. We follow the IIASA estimate that indicates a decline of the U.S. share to 17 percent in the year 2030 (7). Hence, the U.S. may be said to have access to the global sink for an additional 140 billion tons of carbon by the middle of the next century. It will be noted that this limit was exceeded in our base run during which 240 billion tons were generated by 2050.

There are a number of mechanisms for control of CO_2 generation. Quantitative limits may be placed on fossil fuel use by legislation or edict and the powers of the state used to enforce such limits. Such centralized decision making may be contrasted to schemes of taxes or subsidies so calculated that they guide decentralized private decisions to use fossil fuels in the appropriate amounts. Or CO_2 control systems may be devised to remove CO_2 at the generation source, or to remove CO_2 from the atmosphere. A penalty tax system that encourages decentralized decisions to reduce fossil fuel use has attractive features and is consistent with the market interpretation given to the ETA-MACRO model.

It will be recalled that the price elasticity of demand over the long run for an energy resource will converge to the elasticity of substitution value (0.33 in our case). By imposing a penalty tax we are in effect raising the input price of fossil fuels to producers who will either reduce output, or substitute other cheaper inputs, or both. Our procedure was to impose that level of penalty taxes that would reduce fossil fuel use so that our constraint on CO_2 was met. The tax was zero until the year 2010; a tax of $2/million Btu was then imposed until the year 2030. From 2030 to

Table 4

CO_2 EQF (CARBON DIOXIDE ENVIRONMENTAL QUALITY FUNCTION)
CO_2 EDF (CARBON DIOXIDE ENVIRONMENTAL DAMAGE FUNCTION)

A. CO_2 EQF	Energy Resource	Carbon Content (10^9 tons carbon per 10^5 btu)
	Coal and lignite	0.0279
	Crude petroleum and natural gas	0.0239
	Nuclear energy	0
	Fusion energy	0
	Solar energy	0

B. CO_2 EDF	Planet Latitude (degrees)	Effect of Doubling Atmospheric CO_2 on Surface Temperatures (ignoring regional variations)
	0-30	+2 degrees centigrade
	40	+3
	50	+3.5
	60	+4
	70	+6
	80	+8
	90	$+10^+$

Data Source: References (3) and (4).

2055 the tax was raised to $18/million Btu. This latter rising penalty tax rate may be interpreted as the shadow price of dumping carbon by weight into the atmosphere.

Several results may be pointed out before allowing the reader to draw his or her own conclusions from Table 5. In our policy affected run as may be seen in row section 7, CO_2 emissions have been kept within the desired constraints. Imposition of penalty taxes brings about decisions at the production level to substitute alternative energy technologies without a marked reduction in GNP and consumption in 2050. That is, in terms of well-being or welfare, it is highly beneficial for the economy to have alternative energy technologies on hand to turn to if undesirable traits of existing, dominant technologies manifest themselves.

The major energy technology that takes up the slack is the liquid metal fast breeder reactor (FBR) which provides about 90 percent of electricity generation and about 50 percent of total domestic energy production at the end of the period. The cost and other input data assumed for this technology in ETA-MACRO do not pertain to the most efficient breeder attainable so in that sense this study has been conservative in its use of assumed data.

The introduction of the breeder is constrained by the requirement that sufficient plutonium be made available for start-up activities. This constraint is relaxed over time by breeding ratios above unity; but, it should be noted that the plutonium constraint acted in the interval 2030 to 2040 to limit further increases in breeder capacity. Alternative energy technologies such as solar or fusion were too expensive to make a contribution at this point. The reduction in well-being during this time interval provides a vivid example of the social cost of not having completed the alternate energy technology research, development, and deployment strategies in advance.

Penalty taxes on fossil fuels during the early phase of our historical experiment make the light water reactor first generation nuclear technology cost effective, and as may be seen from row section 1.3 of Table 5 the LWR system provides over 40 percent of domestic energy production by 2010. This increase in the use of the LWR given the uranium consumption efficiencies assumed in ETA-MACRO drives up the price of natural uranium to the point in 2010 that the breeder becomes economically attractive. The rapid deployment of the breeder after 2010 would conserve uranium and slow the rise in its price, hence allowing the LWRs to be viable through the year 2030.

The elasticity of substitution plays an important role in our study and it will be worthwhile running sensitivity tests in this respect. Our preliminary work in this area using a value of 0.5 indicates that our major results hold up well. Alternative base case growth paths, both lower and higher, would provide interesting comparative runs. Additional environmental quality constraints could be introduced that affect the choice of energy technologies. New information on energy resources could be introduced to test the value of backstop or social insurance energy technologies such as the breeder in providing alternatives to existing dominant technologies. Finally it would be valuable to test the robustness of our results by constructing comparative runs with other well-known long run energy-economic models.

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Table 5

POLICY AFFECTED RUN RESULTS
(ESUB = 0.333)

	1980	1990	2000	2010	2020	2030	2040	2050
1. Domestic Energy Production (Quads)	61.41	72.82	100.67	136.74	173.51	208.25	237.56	302.83
1.1. Coal, Total:	15.40	19.59	21.89	24.13	29.75	43.51	43.18	38.40
A. For Electricity Generation	11.31	12.38	8.92	5.18	0.37	0.12	0.14	0.19
B. For Synthetic Fuels	0.0	0.75	3.75	7.50	15.00	25.77	22.02	13.77
C. Direct Use and Other	4.09	6.46	9.22	11.45	14.38	17.62	21.02	24.43
1.2. Petroleum and Gas	40.01	40.00	40.00	32.91	24.70	18.96	14.62	11.28
1.3. Nuclear Electricity, Total	3.00	8.67	30.59	67.06	101.07	121.26	142.66	200.21
A. LWR	3.00	8.67	30.25	60.13	55.06	34.81	7.13	5.53
B. FBR	0.0	0.0	0.34	6.92	46.01	86.46	135.53	194.68
C. Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.4. Advanced Electric	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.5. Shale-Oil, Tar Sands, Etc.	0.0	0.50	2.50	5.00	7.00	6.70	9.53	12.00
1.6. Hydro., Geothermal, Etc.	3.00	4.06	5.69	7.65	10.28	13.82	18.57	24.95
1.7. Unconventional Nele	0.0	0.0	0.0	0.0	0.70	4.00	9.00	16.00
2. Petroleum and Gas Imports (Quads)	14.50	13.31	8.57	6.18	3.96	0.0	0.0	0.0
3. Total Energy Consumption (Quads)	75.91	86.14	109.24	142.93	177.47	208.25	237.56	302.83
4. Electricity Generation (Trillion KWH)	2.37	3.00	4.78	8.00	11.17	13.52	16.14	22.54
4.1. % Hydro., Geothermal, Etc.	12.66	13.53	11.91	9.56	9.20	10.22	11.51	11.07
4.2. % Fossil Electric	74.68	57.57	24.04	6.64	0.34	0.09	0.09	0.09
4.3. % Nuclear	12.66	28.90	64.05	83.80	90.46	89.69	88.40	88.84
4.4. % Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5. Resource Requirements, Cumulative From 1980								
Petroleum and Gas (Quads)	200.05	600.05	1000.05	1331.10	1592.24	1794.56	1950.79	2071.36
Coal (Quads)	76.99	250.80	462.26	697.57	987.92	1398.11	1830.72	2228.53
Natural Uranium (Million Short Tons)	0.0792	0.3682	1.2011	2.7327	4.1822	5.1847	5.3448	5.5036
6. GNP (Trillions of 1980 Dollars)	2.623	3.540	4.812	6.121	7.589	8.611	9.821	12.040
Consumption	2.307	3.009	4.072	5.319	6.590	7.428	8.479	10.520
Investment	0.316	0.531	0.740	0.802	0.999	1.183	2.342	1.520
Energy Costs	0.228	0.320	0.447	0.735	0.904	1.667	2.521	2.875
7. Environmental Quality Cumulative Carbon Content (Billions of Tons)								
Fossile Fuel Total	8.66	26.39	44.80	62.42	79.56	97.60	115.56	132.30