A SURVEY OF UNITED STATES AND TOTAL WORLD PRODUCTION, PROVED RESERVES AND REMAINING RECOVERABLE RESOURCES OF FOSSIL FUELS AND URANIUM AS OF DECEMBER 31, 1976

by

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In this report, current estimates are presented for U.S. and world nonrenewable energy sources. The data are presented in summary form due to space limitations. The full paper, available on request from the authors, presents full details of the resource estimates. U.S. fossil fuel resources are reported as of December, 1977. However, for the summary world resource tables, 1976 U.S. data were used to be consistent with the latest estimates available for other world areas.

U.S. Nonrenewable Energy Sources

The following tables present estimates for the remaining recoverable U.S. fossil-fuel resources. Table 1 summarizes the estimates for natural gas made over the past several years by recognized agencies: the American Gas Association (A.G.A.), the Potential Gas Agency, the U.S. Geological Survey (U.S.G.S.), the National Academy of Sciences (NAS), IGT, and some oil and gas producing companies. Table 2 summarizes recent crude oil estimates made by the American Petroleum Institute (A.P.I.), U.S.G.S., NAS, and others. In view of the considerable disagreement among the published data, a high degree of accuracy cannot be claimed despite the unquestionable expertise of the agencies involved.

Remaining recoverable resources as of year-end 1977 are given in Table 3 for the various fossil fuels based on the publications of the above agencies, and the U.S. Bureau of Mines. As in Tables 1 and 2, resources are reported both for the portions qualifying as proved reserves and for the estimated total remaining economically recoverable resources. In both cases recovery is to be economical with current technology. Because of uncertainties, ranges of total remaining recoverable resources have been used for most of the fossil fuels.

U.S. Life Expectancy

Table 4 shows the life expectancy of U.S. fossil fuels in the aggregate (including shale oil and bitumens), with consumption based solely on domestic production and increasing at various fixed annual rates of growth - 2%, 3%, and 4%. It is also based on reducing the resources to a 10-year forward reserve at the annual production rate ultimately reached. For example, if the demand for fossil fuels were to grow at 3%/year, the listed total remaining recoverable fossil fuels would last another 85 years under the conditions stipulated. If restricted to the reserves currently proved, the life expectancy would drop to 32 years. However, if the total remaining recoverable resources could be augmented to twice the present estimated level

Table 1. Estimates of Remaining Recoverable U.S. Natural Gas Resources at Year-End

Year End	Source	Potential Supply: Old Fields	Potential Supply: New Fields	Proved Reserves A.G.A.	Total
		trillion cubic feet			
1977	American Gas Association	--	--	209	--
1976	Potential Gas Committee	215	733 (708-758)	216	1164
1974	Exxon	111 (56-321)	287 (127-657)		635 (420-1215)
	U.S. Geological Survey (Miller, Thomsen, et al)	201.6	484 (322-655)		923 (761-1094)
	National Academy of Sciences	118.6 (calcd)	530	237	886
	Moody	65	485		787
	Average, some major oil cos. (Garrett)	100	500		837
1973	Mobil Oil Corp. (Moody and Geiger)	65	443	250	758
1972	U.S. Geological Survey (McKelvey)	130-250	1000-2000	266	1396-2516
	Potential Gas Committee	266	880		1412
	IGT (Linden)	634 (old and new fields)			900
1971	U.S. Geological Survey (Hubbert)	130 (calcd)	361	279	770
	IGT (Linden)	575-704 (old and new fields)			854-983

Table 2. Estimates of Remaining Recoverable U.S. Crude Oil Resources at Year-End

Year End	Source	Potential Supply: Old Fields	Potential Supply: New Fields	Proved Reserves A.P.I.	Total
		Billion bbl			
1977	American Petroleum Institute	--	--	33.7	--
1976	American Petroleum Institute	--	--	35.2	--
1974	Exxon, rev.	59	63	41	163
	Exxon	57 (36-90)	55 (20-129)	34.25	146 (90-253)
	U.S. Geological Survey (Miller, Thomsen, et al.)	23.1	50-127	38.9	112-189
	National Academy of Sciences, Incl. natural gas liquids	22.7 (calcd)	105-120	45.3	173-188
1973	Mobil Oil Corp. (Moody and Geiger)	11 (calc)	88	40.4	139
1972	U.S. Geological Survey, Incl. natural gas liquids (McKelvey)	24-45	200-400	48.3	272-493
1971	U.S. Geological Survey (Hubbert)	18 (calcd)	55	43.0	116
1970	U.S. Geological Survey, Incl. natural gas liquids (Theobald, et al.)	450 (old and new fields)		52.1	502
	National Petroleum Council	--	--	--	339

in some way (i.e., imports), they would last 108 years. Some recent forecasts suggest that the growth rate of consumption might decrease to 2.5% or less. Hence, there should be adequate lead time to develop synthetic fuels from coal, oil shale, and bitumens, and allow use of the quantities of these materials suggested in Table 3.

Table 3. U.S. Fossil Fuel Resources as of December 31, 1977

	Proved and Currently Recoverable		Estimated Remaining Recoverable	
Dry Natural Gas				
Trillion CF	209		760-1170	
Quintillion (10^{18}) Btu		0.21		0.78-1.19
Natural Gas Liquids				
Billion bbl	6.0		21-33	
Quintillion Btu		0.02		0.09-0.13
Crude Oil				
Billion bbl	29.5		144-371	
Quintillion Btu		0.17		0.84-2.15
Coal				
Billion short tons	214		1036-1788	
Quintillion Btu		4.72		20.71-35.75
Shale Oil				
Billion bbl	74		1026	
Quintillion Btu		0.43		5.95
Bitumens				
Billion bbl	2.5		15	
Quintillion Btu		0.01		0.09
Total, Quintillion Btu		5.56		28.46-45.26

4. Life of U.S. Fossil Fuel Resources At Various Demand Growth Rates (Based on 1977 Year-End Estimates)

Annual Growth Rate, %	Date When Remaining Reserve/Consumption Ratio Drops to 10 Years		
	A	B	C
4	2004	2046	2063
3	2009	2062	2085
2	2015	2090	2123

A Proved reserves (5.56×10^{18} Btu)
B Total remaining recoverable resources (36.9×10^{18} Btu).
C Effective doubling of B resources.

World Nonrenewable Energy Sources

Proved recoverable and total remaining recoverable resource data for the world are shown in Table 5 in conventional units and in the common energy units Btu and metric tons of coal equivalent (tce).

World totals for proved recoverable and total remaining recoverable resource data for the world on a regional basis are shown in Table 2 in conventional units. The total remaining recoverable resources include proved reserves. Natural gas and crude oil proved reserves for the various regions are based primarily on the annual estimates for the component countries published by World Oil and by Oil & Gas Journal. Natural gas and crude oil remaining recoverable resources over and above proved resources are based on published estimates by a number of authorities.

Table 5. Nonrenewable World Energy Total Resources
(December 31, 1976)

	Proved and Currently Recoverable	Estimated Total Remaining Recoverable
Natural Gas		
Trillion (10^{12}) CF	2118-2450	9090-9490
Billion (10^{9}) tce	79-91	337-352
Quintillion (10^{18}) Btu	2.18-2.52	9.36-9.78
Natural Gas Liquids		
Billion bbl	56-65 (Est.)	241-251 (Est.)
Billion tce	8.3-9.6	36-37
Quintillion Btu	0.23-0.27	0.99-1.03
Crude Oil		
Billion bbl	538-606	1500-1840
Billion tce	112-127	313-384
Quintillion Btu	3.12-3.52	8.70-10.67
Syncrude From Oil Shale and Bitumen		
Billion bbl	270	2415 (17,500)*
Billion tce	56	504 (3654)*
Quintillion Btu	1.57	14.01 (101.5)*
Coal		
Billion short tons	662	5367-6119
Billion tce	492	3864-4406
Quintillion Btu	13.67	107.34-122.38
Total Fossil Fuel Energy		
Trillion tce	0.748-0.776	5.054-5.683
Quintillion Btu	20.8-21.5	140.4-157.9
Uranium Oxide at <$30/lb		
Thousand short tons	2443	6624
Burner Reactors		
Trillion tce	0.035	0.093
Quintillion Btu	0.977	2.570
Breeder Reactors		
Trillion tce	2.64	6.94
Quintillion Btu	73.28	192.7
Total Fossil Fissile Energy		
Burner Reactor		
Trillion tce	0.783-0.811	5.147-5.776
Quintillion Btu	21.7-22.5	143.0-160.4
Breeder Reactors		
Trillion tce	3.386-3.414	11.992-12.621
Quintillion Btu	94.0-94.8	333.1-350.6

* See footnote (††)in Table 6.

Note: In the conversion from conventional to energy units the assumed energy equivalents are:

1031 Btu/CF of natural gas
5.8×10^6 Btu/bbl of crude oil or syncrude
4.1×10^6 Btu/bbl of natural gas liquids
20×10^6 Btu/short ton of coal (mixture of types), except for U.S. proved reserves where 22×10^6 Btu/short ton was used
400×10^9 Btu/short ton of U_3O_8 in burner reactors
30×10^{12} Btu/short ton of U_3O_8 in breeder reactors
No plutonium recycle is assumed for burner reactors.
1 tce = 27.778×10^6 Btu.

Table 6. Nonrenewable World Energy Resources By Region (December 31, 1976)

	Proved and Currently Recoverable	Estimated Total Remaining Recoverable
	Billion (10^9) Units	
United States		
Natural Gas, 1000 CF	216	790-1160
Natural Gas Liquids, bbl	6.4	21-31
Crude Oil, bbl	30.9	148-374
Shale Oil, bbl	74	1026 (2000) ††
Bitumens, bbl	2.5	15
Coal, short tons	215	1036-1788
Uranium Oxide*		
short tons at <$15/lb	410	1675
short tons at <$30/lb	680	3370
Western Hemisphere (Incl. U.S.A.)		
Natural Gas, 1000 CF	352-382	2546-2946
Natural Gas Liquids, bbl	9.3-10.1	67-78
Crude Oil, bbl	66-71	320-420
Shale Oil, bbl	130	1500 (5000)
Bitumens, bbl	80	500
Coal, short tons	224	1114-1866
Uranium Oxide*		
short tons at <$15/lb	628	2345
short tons at <$30/lb	955	4331
Europe (Excl. U.S.S.R.)		
Natural Gas, 1000 CF	152-173	484
Natural Gas Liquids, bbl	4.0-4.6	13
Crude Oil, bbl	19-26	39-79
Shale Oil, bbl	15	150 (1400)
Bitumens, bbl	N.A. †	N.A.
Coal, short tons	141	356
Uranium Oxide*		
short tons at <$15/lb	76	129
short tons at <$30/lb	621	914

Table 6. Nonrenewable World Energy Resources By Region (cont.)
(December 31, 1976)

	Proved and Currently Recoverable	Estimated Total Remaining Recoverable
	Billion (10^9) Units	
Asia - Pacific (Incl. European U.S.S.R.)		
Natural Gas, 1000 CF	1415-1672	5064
Natural Gas Liquids, bbl	37.5-44.3	134
Crude Oil, bbl	402-445	1005-1175
Shale Oil, bbl	35	115 (6500)
Bitumens, bbl	N.A.	N.A.
Coal, short tons	280	3865
Uranium Oxide*		
short tons at <\$15/lb	322	427
short tons at <\$30/lb	367	501
Africa		
Natural Gas, 1000 CF	199-223	996
Natural Gas Liquids, bbl	5.3-5.9	26
Crude Oil, bbl	50-63	136-166
Shale Oil, bbl	10	100 (4100)
Bitumens, bbl	N.A.	N.A.
Coal, short tons	17	32
Uranium Oxide*		
short tons at <\$15/lb	370	423
short tons at <\$30/lb	500	677

* Thousands of units
† Not available
‡ Values in parenthesis include estimates of undiscovered or unappraised resources in the 25-100 gal/ton yield range according to Duncan and Swanson, "Organic-Rich Shale of the United States and World Land Areas," U.S. Geol. Surv. Circ. 523.

Coal resource data are those of the World Energy Conference 1974 Survey of Energy Resources, except for the United States, where U.S. Bureau of Mines data are used. Allowance has been made for recent production; a mining loss of 50% is assumed.

Uranium oxide (U_3O_8) resources are expressed in terms of the U_3O_8 content of ores and forward cost rather than the actual market price, which has been rising rapidly. No allowance is made in forward cost for amortization of capital, financing cost, or profit. The U.S. data, from ERDA, are as of year-end 1976; all other data, reported jointly by the European Nuclear Energy Agency and the International Atomic Energy Agency, are as of year-end 1974. The communist countries' resources are excluded due to the lack of suitable data.

Both 1976 production and cumulated production of natural gas, petroleum, coal, and uranium oxide are shown in Table 7. Cumulated production data for the United States come from the U.S.G.S. and ERDA and have been updated by the use of recent production data.

Estimates of life expectancy of world fossil resources based on the quantities given in Table 1 and on the current production rate increasing at selected fixed annual growth rates are shown in Table 8. Fortunately, the life expectancy of remaining recoverable world fossil fuel resources, as now estimated, is of the order of 100 years at a reasonable growth rate of 2% to 3%/yr.

Table 7. Nonrenewable Energy Sources Current and Cumulated Production

	Natural Gas Trillion CF	Petroleum,* Billion bbl	Coal, Billion short tons	U_3O_8, 1000 short tons
World				
1976	54-55	21.1	4.2	[26]†
Cumulated	888-913	359-366	154	572
United States				
1976	19.8	2.97	0.671	12.7
Cumulated	519	112.0	44.2	295

* Gross minus reinjection.
† Estimate.

Table 8. Life of World Fossil Fuel Resources
At Various Fixed Demand Growth Rates
(Based on 1976 Year-End Estimates)

Annual Growth Rate, %	Year When Remaining Reserve/Consumption Ratio Drops to 10 Years		
	A	B	C
4	2005	2050	2067
3	2010	2067	2090
2	2017	2097	2130
1	2029	2164	2226

A: Proved reserves: 0.748 to 0.776 x 10^{12} tce; mean = 0.762 x 10^{12} tce.

B: Total remaining recoverable resources: 5.054 to 5.683 x 10^{12} tce; mean = 5.369 x 10^{12} tce.

C: Doubling of estimated B resources.

Note: Calculations are based on growth at fixed selected annual increases of 1% to 4% from the 1976 world annual production of 8.695 x 10^9 tce, as estimated by the U.N.

Peat Resources

Although peat has been used as a fuel for centuries, it is not included in conventional resource estimates because of the general lack of information on the extent of the reserves and the potential contribution to world energy supply. Some incomplete data on world peat resources is shown in Table 9. Based on available data peat lands occupy an estimated 408.8 million acres of land in the world. These data show that the Soviet Union has 228 million acres, about 56% of the total world peat resource area-wise. The Soviet Union annually produces some 205 million tons, about 95% of the world's annual production. Total acreage of peat land in the U.S. is 52.6 million acres. Finland ranks third in total extent of peat lands and Canada fourth. It is to be noted that the resources listed for Canada exclude the Arctic regions. If these were included it is likely that the Canadian resources would be much higher than shown, and Canada would probably rank second to Russia in total peat resources.

Currently, only Russia, Ireland and Finland use large quantities of peat for fuel, mostly for generation of electric power. Research underway to convert peat to gaseous and liquid fuels could result in an accelerated development of this somewhat neglected energy source.

The basic problem with estimation of peat resources is that while the areal extent of peat deposits is fairly well known, data on the thickness of such deposits is sparse. Therefore, estimates in terms of energy content are difficult to make.

Table 9. World Peat Resources and Annual Production (1)

Country	Acres	Annual Production	
	(millions)	(%)	(million tons)
U.S.S.R.	228.0	95.70	205.0
U.S.A.	52.6	0.30	0.6
Finland	35.6	0.36	0.7
Canada (Excluding Arctic)	34.0	0.25	0.5
E-W Germany	13.1	1.00	2.0
Great Britain and Ireland	13.1	2.00	4.2
Sweden	12.7	0.15	0.3
Poland	8.6	--	--
Indonesia	3.3	--	--
Norway	2.6	--	--
All others	5.2	0.4	1.2
TOTALS	408.8	100.0	214.5

General Comments on Reserve Changes and the Future Role of Economically Marginal Resources

The crude oil reserve estimates shown in Table 6 do not include the most recent upward revision in Mexico. The proven reserves of January 1976, amounting to 6.3 billion barrels have been increased to 20.24 billion barrels as of July 31, 1978. In addition, probable reserves are estimated at an additional 37 billion barrels and potential reserves, including the proven and probable volumes, may be on the order of 200-300 billion barrels. Further exploration and development may place Mexico in the same rank as Saudia Arabia in terms of oil resources.

The oil reserves of mainland China could also be much larger than current estimates based on available information. One recent estimate places proved, probable and possible recoverable reserves at 100 billion barrels. Major exploration and development efforts will be necessary to confirm or amend this figure.

A recent assessment of giant oil fields and world oil resources, not included in the base data used for reporting world oil reserves, has been made by the Rand Corporation[2] for the Central Intelligence Agency. The author concludes that, as of the end of 1975, proved and probable recoverable world crude oil reserves were 676 billion bbl, compared with the 538-606 billion bbl shown in Table 5. However, the Rand figure includes some probable reserves in addition to the generally accepted data for proved and currently recoverable reserves. It is pointed out that the difference between the Rand estimate and those made by other authorities is probably due to a) the definitions of probable reserves used in various estimates, b) the extent to which reserves and recent discoveries are included and c) the differences in various estimates of known total recovery in the Soviet Union. The Rand estimate of ultimate conventional world crude oil resources is in the range of 1,700 - 2,300 billion barrels. If the estimated prior production of 335 billion bbl is subtracted, the total remaining recoverable reserves would be in the range of 1,450 - 1,950 billion bbl, which corresponds very closely to the IGT estimate of 1,500 - 1,840 billion bbl.

A major unknown in estimates of oil reserves is the extent of heavy oil resources which may become exploitable at higher prices. For example, the Orinoco oil sands in Venezuela, with a resource base of 4 trillion barrels, may extend from the eastern slopes of the Andes to Argentina, Bolivia, Peru and Brazil. The resource base for heavy crudes in place in this area may exceed those estimated for Venezuela alone. The extent to which these resources are economically recoverable with current technology is not known, but is probably rather low.

The estimates of world gas reserves presented herein do not include the so-called "non-conventional" sources of natural gas, because such sources cannot be estimated within the framework of the conventional procedures used for reserve evaluation. However, they could become a very important source of future energy supplies as reamining conventional resources decline. In general, such resources are not recoverable under current or near-term economic conditions. The sources are shales of the Mississippian and Devonian age, tight gas formations, coal seams, geopressured aquifers, and gas hydrates. The data base for even preliminary evaluation of these resources is very scanty. However, due to the recent shortage of conventional gas supplies in the United States, these resources are being evaluated by the U.S. government agencies for potential future gas supply. As a result, most of the available data are applicable only to the U.S. situation.

The resource base of gas existing in the Devonian and Mississippian shales in the eastern U.S. is estimated to be on the order of 600 trillion cubic feet. There has been a small amount of production from these shales in the Appalachian area for many years. Major efforts are underway to more rigorously define the resource and to develop means of substantially increasing production rates from wells.

Large areas of gas-containing formations which are relatively impermeable to gas flow exist in the western U.S. (and also in western Canada). The resource base in the U.S. is estimated at 600 trillion cubic feet. Application of advanced fracturing techniques could result in recovery of substantial quantities of this gas.

Many coal seams in the world contain appreciable amounts of natural gas which may be recoverable by specialized drilling and drainage techniques. For the U.S., the resource based of methane associated with coal is estimated at 2,500 trillion cubic feet.

A belt of geopressured aquifers in the gulf coast region of the United States contains brine saturated with natural gas at pressures higher than the hydrostatic head from the surface to the formation. The lack of information on the extent and producibility of the aquifers has resulted in a very wide range for the methane resource estimate - 3,000 to 100,000 trillion cubic feet. Major experimental efforts are underway to more rigorously define the resource base and to devise methods of producing the resource in an economic and environmentally acceptable manner.

The least well-defined and most speculative natural gas resource is gas hydrates. A gas hydrate is a solid compound of methane and related hydrocarbon and water which exists at a relatively low temperature and relatively high pressure. Deposits of gas hydrates have been discovered in Siberia and there is indirect but rather compelling evidence that gas hydrates exist in the North American Arctic regions and in the deep ocean bottom. Some Russian scientists[3] have estimated that the world resource base of submarine gas hydrates is on the order of 1×10^{18} cubic meters. To date, no definitive progress has been made in further assessing the extent of this resource or the development of methods for recovery.

Although these unconventional gas resources have been discussed primarily in the context of U.S. experience there is every reason to believe that similar resources exist on a worldwide basis. Of the various sources, the resource base of natural gas associated with coal is probably the most amendable to estimation. Insufficient data are available on the remaining sources although tight sands, shales comparable to the eastern U.S. sources and high pressure zones encountered during oil drilling in other parts of the world lend credence to the belief that similar conditions exist outside the U.S. Only a very small fraction of these resources is producible under current economic conditions. However, as the decline of more conventional supplies of oil and gas forces the price up, the unconventional sources may provide an expanding source of future gas supply.

Another very large potential source of fossil energy is the lower grade oil shales. Recent experimental work by the Institute of Gas Technology has demonstrated that yields of oil from shales of 10-15 gal. oil per ton (by Fischer Assay), using a hydroretorting technique, gives energy recovery equivalent to the conventional retort yield from richer western U.S. shales. The estimated resources in four U.S. eastern states recoverable by above-ground hydroretorting are equivalent to 414 billion bbl oil. A similar resource base is very likely to exist in other parts of the world.

The combined effect of future higher energy prices and advanced technology could permit eventual massive exploitation of non-conventional gas supplies, low grade oil shale, peat, currently unmineable coal deposits and other currently economically marginal or uneconomic fossil energy supplies. In view of the potential size of the resource base, the rationale of doubling the current estimated remaining recoverable resources (Tables 4 and 8) to estimate U.S. and world possible extended fossil fuel resource life seems justified.

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WORLD ENERGY SUPPLY AS A PRICE DEPENDENT VARIABLE

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Introduction

In the area of energy resource management, more uncertainties have developed in the last five years than in the previous twenty. In Figure 1, the posted price (real and current) of world crude oil is shown from 1960 through 1978. After a long period of relative stability, this price rose from $2.59 per barrel to $11.65 per barrel in one year (1973). A strong cartel (OPEC) developed that now asserts control over a large fraction of petroleum traded in international markets. This development has substantially affected the price outlook for other fuels as well. International energy markets and other segments of world economies have been changing rapidly in the past five years in a still emerging response to the formation of the cartel.

A common perception of the future[1,2] is that there will be increasing disparity between growing demand and dwindling non-OPEC supplies and ever rising energy prices. In this view, the United States and other major industrial nations are confronted with the likelihood of a growing need for oil imports and greater dependence on foreign supplies. The resulting political and economic problems impel government and business planners to consider alternative responses.

In a recently completed two-year study of world energy supply and demand at SRI International, a somewhat different picture of the likely developments in future world energy balances has been obtained.

Summary

The principal conclusion of our analysis of world energy supply and demand is that there are adequate opportunities for increasing conventional supplies of hydrocarbon resources on a worldwide basis, diversifying the sources of supply, and substituting among fuels to allow an orderly development of alternatives through the remainder of this century and for some time into the next without large price increases. This conclusion is based on the following series of observations and estimates:

- The conventional techniques used to make estimates of resource availability in terms of a single number representing reserves are not adequate information to determine future supply/demand balances. Resource availability should be discussed in terms of recovery costs and market prices.

- There is no long-term condition of imbalance in supply and demand where "gaps" occur. In the absence of artificial price controlling regulations, prices respond well in advance of this impending situation to prevent just such a possibility.

- International energy supply and demand price elasticities have been broadly underestimated.

- Current estimates of proven oil reserves do not accurately reflect the long-range impact of higher petroleum prices. Higher oil prices are encouraging exploration and the application of advanced recovery techniques so that future additions to proven reserves will be greater than they would have been at lower oil prices.

- The opportunities for fuel substitution are greater than has generally been recognized.

- There will be an expansion of the class of major oil exporting nations to include some new members in the next few years (Mexico, the United Kingdom, Norway, China, etc.). The disparity of national interests will cause highly varied responses to changing supply/demand situations in the world markets. Those who join OPEC will increase the diversity of cartel membership and the complexity of production allocation and pricing decisions to be settled.

This view of world energy availability has not been the consensus. As mentioned earlier, many other analyses anticipate serious supply/demand imbalances in the 1980s. These different viewpoints arise principally from certain features of the present analysis described below that are not usually considered in this kind of study. These features do not eliminate the substantial uncertainties inherent in this kind of analysis from unanticipated political, social, or technological developments (e.g., wars, embargoes, a major depression, or a breakthrough in photovoltaic cell economics, etc.), but they do provide a powerful tool for evaluating the potential sensitivity of the results to these changes.

<u>The Analytical Structure</u>

It has been customary for energy analysts to hypothesize a "scenario" price or set of prices for some reference energy source, usually Middle East oil, and then try to determine how the demand for oil will grow and what supplies will be produced at this price. In that approach, demand is growing exponentially and supplies are relatively static. It is not surprising then that at some point demand exceeds the supply, creating an "energy gap."

The procedure outlined above simplifies the analysis by ignoring the feedback among energy supply, demand, and prices, and the effects of prices on interfuel substitution. That approach is not complete, however, because it ignores the dynamics of energy pricing through time.

Energy prices respond not only to the instantaneous supply/demand balance but also to producers' and consumers' perception of the future. If a producer perceives that his resource is growing scarce because of depletion of the reserves, he will demand higher prices now for incremental production. How much he can raise his price depends upon a variety of time dependent variables including:

- The rate at which the resource is being depleted now and what rate might be expected in the future

- That producer's potential loss of market share to other producers of the same resource or to competing substitutes or to declining demand

- The impact that higher prices would have on the stimulation of new technology to replace future demand for the product

- The individual producer's preference for present income versus deferred, perhaps higher, income at some future time.

Therefore, at any given time in energy markets, a variety of individual decisions are being made by producers and consumers that rebalances the supply/demand equations.

The quantitative analysis here has centered around the development of a world energy model[3] built in two parts and called ENDEM and FUELCOM, respectively.

ENDEM (Energy Demand Model) is a representation of our analysis of energy demand development on a regional basis for 15 different end-use categories (steelmaking, chemicals, residential/commercial space heat, transportation, etc.) as a function of assumptions about macroeconomic variables such as population, GNP per capita, and trade balances. FUELCOM (Interfuel Competition Model) represents our analysis of the competition among different fuels (oil, coal, gas, nuclear, hydro, and others) for each of the end-use markets in each region. FUELCOM calculates market clearing prices for each fuel in each region based upon obtaining supply/demand balances at each point in the energy network from resource production, through conversion and transportation links, to end-use consumption in each of the demand markets used by ENDEM.

The approach used in this study to integrate the demand and supply work is an iterative process. At first a tentative economic projection (GNP growth rates, trade flows, industrial production, consumption) is used to calculate tentative energy demand projections by end-use category for each region (at the highest level of regional aggregation) in ENDEM. These projections are used in FUELCOM to obtain an overall energy demand/supply balance at a market clearing price for each fuel in each region over the entire time horizon. This tentative energy balance is compared by the analyst with the assumptions on energy prices and trade flows implicit in ENDEM. If they are consistent and reasonable in the judgment of the analyst, a converged solution is assumed. If they are not consistent, a somewhat revised economic outlook is made to take into account the new information on energy prices and trade flows, and the process is repeated until a converged solution is obtained. When this process is completed at the first level of regional disaggregation and a satisfactory convergence obtained, a further regional disaggregation is begun using the larger region results as constraints on the more detailed analysis.

The principal outputs of the energy model are projections of the regional market clearing prices for fuels over time, associated production quantities, flows through transmission links, capacities of conversion processes, and demands for distributed fuels. Clearly, the projections can be sensitive to the inputs to the model. By varying the key model inputs and assumptions over reasonable ranges of uncertainty, the sensitivity of the projections to these inputs are determined.

Results--Demand

Long-range projections of world energy demand have been changing substantially in recent years. Today's estimate for total primary energy demand for the year 2000 is more than 20 percent lower than earlier estimates.[4] For example, Exxon's recent estimate of world energy demand for the non-Communist world in 1985 of 125 million barrels of oil equivalent per day is down 24 percent from estimates of 165 million barrels of oil equivalent per day made in 1973 for the same region. These differences are related to changing views of the future growth of regional macroeconomic indicators such as GDP and population, as well as to changes in the relationship of energy consumption to these variables and to price. The quadrupling of world oil prices since 1973 (shown in Figure 1) has had an important impact on all of these estimates. Even if demand often appears to be somewhat inelastic to price changes in the short term, long-term effects of the increases shown in Figure 1 are making big changes in year 2000 projections.

The regional variation in anticipated primary energy consumption obtained in this analysis is shown in Table 1. Although OECD nations still account for nearly half of world energy consumption in year 2000, in general, developing nations will show higher growth rates of energy consumption than developed nations because they are starting from much lower absolute values, have higher population growth rates, less room for improvements in the efficiency of consumption, and are expected to make considerable effort to "narrow the gap" in GDP per capita.

The changing relationship anticipated between energy and GDP is most dramatic in the United States. In 1970, a barrel of oil equivalent energy was used to generate about $140 in gross domestic product (in constant 1978 dollars). By the year 2000, it is expected that the same amount of energy will generate about $191 in GDP or a 37 percent increase in economic efficiency in energy use. These efficiency improvements are achieved despite the fact that electricity consumption is expected to grow faster than total energy, and average electric power efficiencies are lower than for the direct consumption of fuels. Such changes are occurring worldwide, although not so dramatically in nations that have historically not had access to the same abundance of relatively low-cost energy as the United States.

Table 1

PRIMARY ENERGY CONSUMPTION
(Millions of Barrels of Oil Equivalent per Day*)

	1960	1970	1980	2000
United States	20.7	31.7	38.9	58.6
Canada	1.8	3.0	4.5	7.3
Western Europe	12.5	22.0	27.3	46.3
Japan	1.8	5.6	8.8	17.9
Mexico/South America	2.2	4.2	7.5	20.9
Africa	1.0	1.8	3.4	7.6
Middle East	0.7	1.4	3.3	10.5
Centrally Planned Economies	18.2	27.1	42.9	87.5
Remainder	2.2	4.6	7.6	19.1
Total	61.1	101.4	144.2	275.7

* For most of this paper, the units of energy demand will be expressed in oil equivalent barrels to evaluate how changes in forecasts or assumptions can affect world oil trade--oil being the "swing fuel" in international energy forecasting.

The results of the FUELCOM interfuel competition analysis corresponding to the ENDEM regional energy demand of Table 1 is shown in the highly aggregated curves of Figure 2. There are no dramatic surprises shown in this figure. World demand for all forms of primary energy is expected to continue to grow to the end of the century but at considerably lower rates than for the most recent 25-year historical period. The average historical growth for 1950 to 1975 was about 5 percent, whereas for the forecast period the analysis indicates world average demand growth of about 3.4 percent.

Oil, coal, natural gas, and nuclear energy are all expected to play major roles in supplying the increased energy consumption, while hydroelectric energy supplies will become increasingly important in some of the less developed areas.

Worldwide, nuclear power generation growth rates, although still considerable, will be substantially lower than most projections of the recent past because of previously unanticipated political, social, and economic problems. Gas consumption, on the other hand, will probably grow more rapidly than expected.

Primary Resource Economics

One of the most difficult and important considerations in analyzing energy supply and demand balances is to quantify the long-term economics of primary resource production. In the classical economic sense, a long-term dynamic supply curve that specifies a price-volume relationship across a 50-year time horizon or longer is required for each resource. The key issues that must be considered with regard to primary resources are: depletion, reserves, lease cost, production, development, exploration, technological change such as enhanced oil recovery or advanced mining techniques, and wellhead or mine-mouth price.

The main shortcoming of most published resource estimates is that price is not explicitly included; only quantity if considered. Differences among estimates can thus be due to differences among assumptions and definitions as well as to differences of opinion or uncertainty about the resource base itself. To analyze strategic energy decisions and to estimate resource availability, considering resource volume estimates alone is not sufficient; joint price-volume relationships for each resource must be estimated and made explicit.

Resource supplies represented in FUELCOM on a regional basis are crude oil, natural gas, coal, nuclear fuel, hydroelectricity, oil shale, and tar sands in specific regions. Each of these is described in each resource basin by a different supply curve giving the marginal cost of incremental production of that resource as a function of total cumulative production in that basin. Probable in-place resources, past discovery and development histories, and expected future finds are defined in the analysis. In estimating the costs of reserves, price-dependent costs such as lease bonus payments, royalties, and production taxes are distinguished from ordinary exploration, development, and production costs.

Specifically excluded from the marginal cost is economic rent (lease bonus payment and additional profits above the 15 percent return on investment). The marginal cost of a resource is the minimum acceptable price at which the supplier would be willing to develop and sell that resource. Economic rent, reflected in a price higher than the minimum acceptable price, is computed by FUELCOM as a function of the prices of other energy sources and the dynamic characteristics of the market. For OPEC producers, a specific cartel pricing algorithm is used.[3]

FUELCOM uses regional marginal cost estimates including 26 oil resource curves, 26 gas resource curves, 22 coal curves, and 13 miscellaneous resource curves, including estimates of the costs of hydropower, nuclear fuel, shale oil, and tar sands in different regions. As an example of this type of curve, Figure 3 illustrates the marginal cost curves for world cumulative supplies of crude oil, natural gas, and coal. These world total curves are much too aggregated for use in FUELCOM, but are valuable to illustrate several important points. As shown, coal is available in vast quantities at low recovery cost. Recently,[5] the estimated in-place coal resource base of the world was increased over 18 percent above the 1974 estimates at the 1978 World Energy Conference. Similar modifications in estimates of traditional supplies of oil and gas are being made showing increases in production potential from old and new areas, e.g., Mexico, China, Canada, the North Sea, etc.

From the results shown in the curves of Figure 2, the cumulative world consumption of oil anticipated from 1975 to 2000 is 700 billion barrels. For natural gas and coal, the cumulative consumption is 340 and 460 billion barrels of oil equivalent, respectively. Although there is not sufficient information in the curves of Figure 3 to calculate a year 2000 market clearing price for each resource, it is apparent that world supplies of these resources are by no means exhausted at the end of the century. In fact, there is considerable uncertainty as to whether the market prices of conventional supplies will even reach the levels required to make sources of synthetic hydrocarbons commercially competitive by that time. Superimposed on the marginal cost resource curves of Figure 3 are the minimum cost estimates found in the literature[6] for synthetic crudes from coal, synthetic natural gas (SNG), and oil from shale. The early 1978 posted price of OPEC marker crude oil is also shown for comparison. In this economic environment, because of price competition from conventional supplies, it is not likely that any unconventional supplies of energy will become commercially available on a global scale before the end of the century. However, in specific locations, shale oil, heavy oils, and synthetic fuels from coal may contribute a measurable fraction of regional energy supplies.

As an example of evolving trade patterns, Figure 4 shows how petroleum production patterns have changed since 1950 and are expected to change in the future. In 1950 there were four significant production areas in the world--North America, Central and South America, the Middle East, and the Soviet Union. By the end of the century, according to this analysis, there will be several more. The Middle East, of course, remains a major supplier of oil to the world, although its share of world markets will be smaller in the future. An important result of this analysis is the growing role of producers that are not presently in OPEC--Mexico, the United Kingdom, Norway, China, and several nations in Africa and Asia. Each is faced with the need to develop supplies and to market them to provide capital for economic development. In addition, considerable development of coal and nuclear resources displaces oil and gas from utility and industrial markets. Since OPEC must continue to function as the marginal supplier of petroleum to maintain control over international oil prices, all of these development impact strongly upon cartel production growth rates and together suggest that--for a time--the organization will find itself in the passive position of attempting to preserve its gains. Future growth in world demand for oil will very likely be significantly slower than the pace that was seen in the years prior to 1974. Non-OPEC oil production will continue to grow, probably at a rate higher than many observers expect. If the organization is to continue to set and maintain the world price of oil, it must also support the price for all producers of oil moving in international trade. Many of the newer oil exporters such as Norway, the United Kingdom, and China are not likely to become part of OPEC because of their history, politics, or because--for one reason or another--they do not view membership in the cartel as in their best interests. A special problem for the cartel is that non-OPEC producers can take advantage of the cartel price without assuming any of the burdens associated with withholding production to support prevailing price levels. As mentioned previously, it is expected that those who do join OPEC will increase the diversity of cartel membership and the complexity of production allocation and pricing decisions to be settled. The combination of these factors is likely to place pressure on OPEC's market share and--at least over the near term--continue to reduce the ability and willingness of cartel members to make higher real prices stick.

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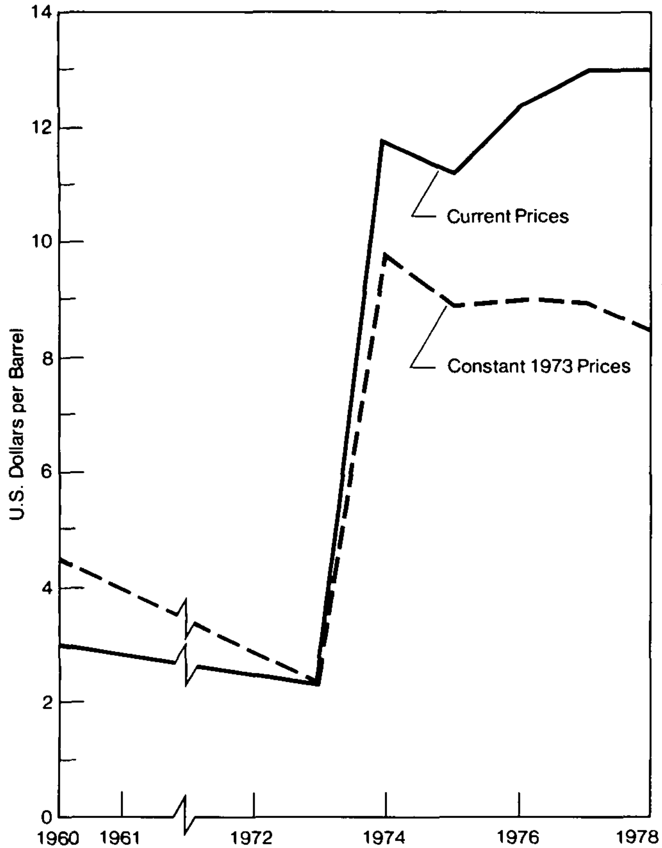

Figure 1. OPEC Prices of Oil

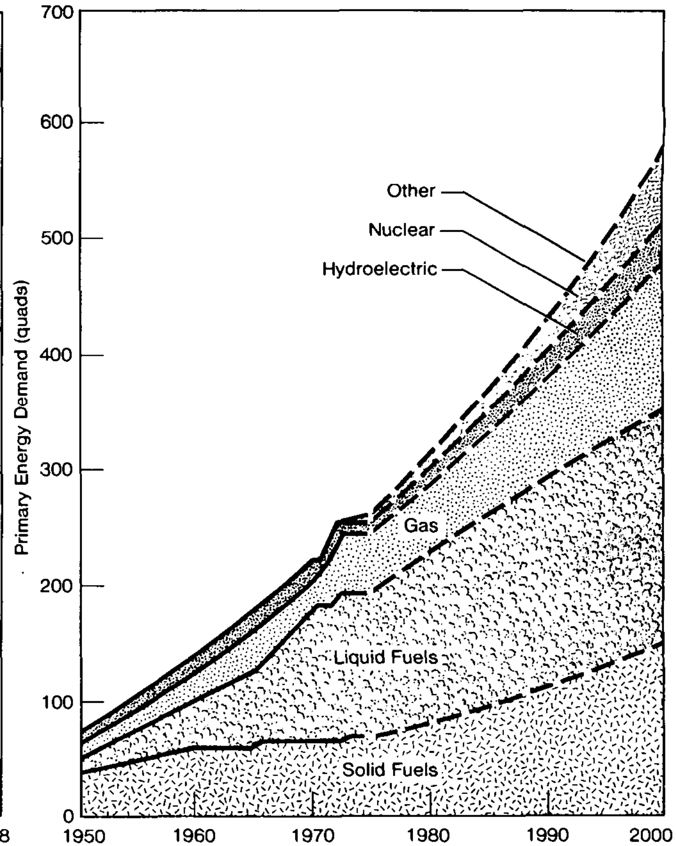

Figure 2. World Energy Consumption

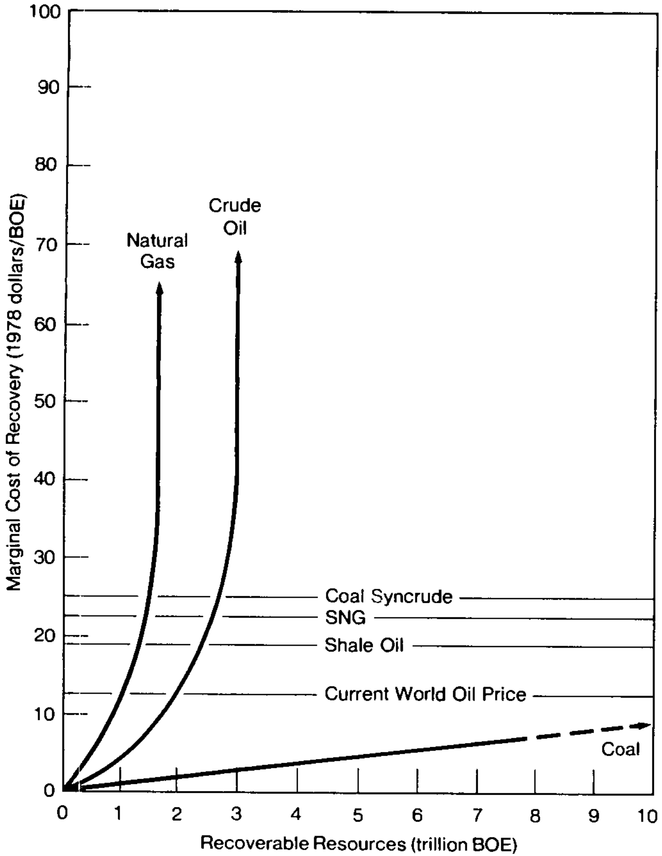

Figure 3. World Hydrocarbon Resources in 1975

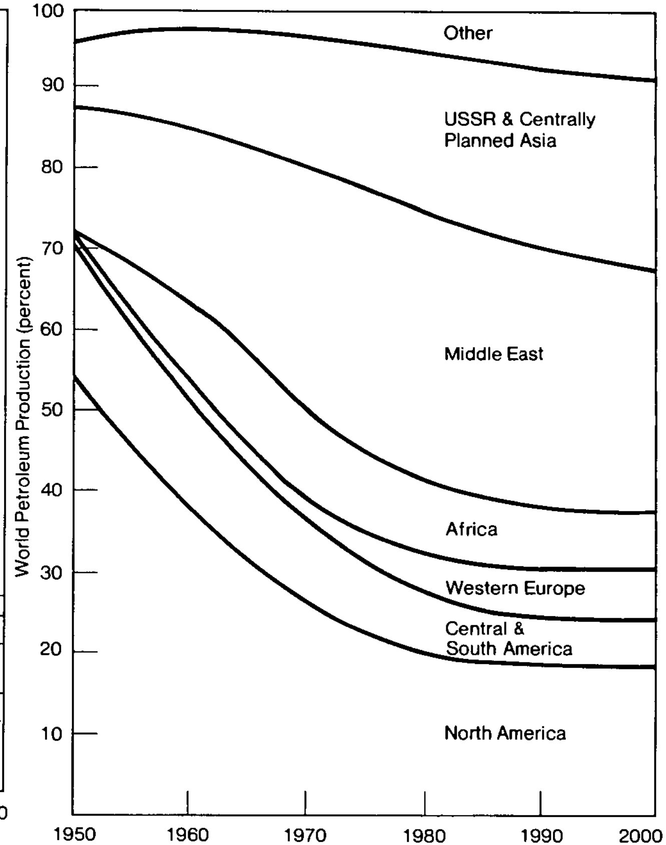

Figure 4. World Petroleum Production

FORETELLING THE ENERGY FUTURE

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Introduction

Half a decade has passed since the world economic system suffered the shock of a massive increase in oil prices. In the intervening years there have been many conflicting forecasts of future energy developments, ranging from "no problem" to alarmist warnings of another, even greater, shock to come - a second energy crunch. The latter variety have tended to predominate. The multiplicity of forecasts would be confusing enough and undoubtedly contribute to indecision and lack of action by the policy makers, but the picture is still further obscured by the current situation. At the time of writing (November 1978), oil consumption is only just back where it was five years ago, energy supply is in potential surplus and the sense of urgency seems to be gone. What is the truth? Is the second energy crunch, so widely predicted, real or not? If it is, how can the confusing messages be rationalized so that the actions necessary to ameliorate it can be set in motion?

A Methodology for Coping with Uncertainty

"Those who foretell the future lie, even if they tell the truth" Arab Proverb

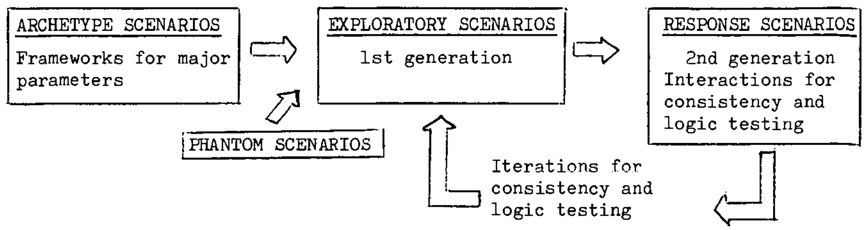
This quote is appropriate at the beginning of a discussion on the future of world energy supply and demand in view of the important role which the Middle East has had, and will continue to have, in shaping the future world energy scene. This particular proverb also makes another very important point - the future cannot be predicted. In fact there are many possible futures dependent on how events and decisions yet to be taken are linked and interact. Assertions about the future in general and about energy developments in particular may or, more likely, may not, turn out to be accurate but if we are to avoid confusion, indecision and too many mistakes, we need a methodology to cope with the uncertainties.

A scenario is logically coherent, future state of the world. It is not what will happen but what can happen - a subtle but important distinction. We can distinguish, and will be referring to, three distinct types of scenario - the archetype, the phantom and the exploratory scenario (see Box 1). Archetype scenarios form a starting point; they provide alternative views of the world or of specific issues in rather stark terms, i.e. the future economic framework, oil price developments etc. Phantom scenarios are similar, but they consider issues which have a low probability of occurring but a major impact on the future if they do occur. Exploratory scenarios are rather different; they combine the variables that emerge as important from the essential analyses of the archetype and phantom scenarios to develop routes or pathways into the future. This involves making assumptions about how the world will react to a given set of conditions, so exploratory scenarios tend to evolve into second generation response scenarios.

The scenarios have several functions. Their construction is a learning process which helps us to understand the past and the present and to structure in a rational way the uncertainties of the future. As a possible instrument of change, they have an important role in strategic planning. By identifying the features common to all scenarios - the pre-determined elements - we provide a hardcore of information, some solid facts on which we can base our plans.

The scenarios also provide a rational framework for discussion with outside organisations such as governments, academic institutions etc. We can thus share our view of the world in an unemotional and professional way. This is particularly important in the international energy sphere, where as we have mentioned, the dialogue has become confused because of the concentration on conflicting single-line forecasts.

SCENARIO DEVELOPMENT — BOX 1



ARCHETYPE SCENARIOS - A pure or prototype scenario describing important scenario aspects in stark, rather black and white terms. A useful analogy comes from psychology where the personality archetypes "introvert" and "extrovert" describe very few actual human beings. However, most of us have elements of both types in our make-up, so an understanding of the two archetype personalities is helpful in analysing and hence understanding individual personalities. In the same way, the construction and analysis of archetype scenarios is helpful in understanding and preparing for the future, even though that future is most unlikely to correspond to a single archetype.

PHANTOM SCENARIOS - These are Devil's Advocate type of scenarios. They have a low probability of occurring but the impact on the future if they do come about is very high indeed. Their ultimate aim is to reinforce the resilience of strategic planning.

EXPLORATORY SCENARIOS - Exploratory scenarios combine the variables that emerge as important from the analysis of Archetype and Phantom scenarios to develop routes or pathways into the future. This involves making assumptions about how the world will react to a given set of conditions, so exploratory scenarios tend to evolve into second generation response scenarios.

Archetype Scenarios for Energy Planning

Energy is fundamental to virtually everything we do. We need it to build and then heat or cool and illuminate our houses, grow our food, power our transport systems and to make all those countless things which we now consider essential to our way of life. Insofar as these all-embracing factors can be described in economic terms, archetype scenarios can be expressed in macro-economic indicators such as GNP growth rates, but this is only the starting point. Energy supply and availability depends on political factors, international trade, the future climate for investment etc. Demand is governed, not only by economics, but also by society's changing attitudes which will be reflected in changing life styles.

Two archetype scenarios are described below (see Box 2), The World of Internal Contradictions (WIC) and Business Expands (BE). Growth, in the sense of increasing added value from man's activity, can be seen as a natural phenomenon in human society. The WIC and BE scenarios differ in the extent to which the barriers to growth are removed or institutionalised. Both scenarios are catastrophe-free i.e. no world wars, and assume that the balance of power between East and West is not seriously disrupted.

A WORLD OF INTERNAL CONTRADICTIONS	BUSINESS EXPANDS BOX 2
- A world which fails to liberate the forces making for growth - Systems proliferate and decay, alienation is widespread - Greater government intervention in the market economy - Diversion of resources to non-marketed sectors. Low commitment of risk capital - Low growth of international trade (protectionism) - Strong move towards further egalitarianism - GDP growth 2.6 - 3.0%	- Barriers to growth removed - Systems performance improved, alienation mitigated - Reached by reaction against low growth The Condition - Effective political leadership - Governments understand and foster the process of wealth creation - Strong links into the international trade system - GDP growth 4 - 4.5%

We can get some idea of how demand for energy might develop by quantifying the archetype scenarios. One way of doing this would be simply to look how demand has increased with economic growth in the past and to project this, or a subjectively modified relationship, into the future. Such type of analyses quickly indicates that demand for energy, and for oil in particular, will grow to exceed available supply - to result in a gap or the next crunch - any time from the early 80's onwards, depending on the economic growth rates chosen. But such an analysis is far too simplistic. The historic relationship between energy and economic growth was established over a long period of abundant, low-priced oil. The oil price hike in 1973/74 was enough to begin to change our way of using energy, our attitudes towards conservation, self-sufficiency etc. and changes in oil price in the future remain a key element in influencing future demand. Hence it became clear that the price-dimension had to be introduced in the energy quantification work as a critical separate variable.

The price of a commodity is normally determined by the supply/demand interplay, i.e. provided supply is free to increase in pace with demand. If there is interference with the free supply/demand play, as there has been in the case of oil, then the price could be driven up to the eventual cost of alternative fuels. In theory, this upper level should provide a new norm for oil prices, but, in practice, because of the long lead times necessary to change the pattern of energy supply, the point at which some consumers, or more particularly consuming countries, will find it difficult to pay may well be reached earlier. Considering the economic disruption that has already been caused by the price rises of 1973/74, it would seem that we are already close to some consumers' ability to pay at current prices. At this stage, economics have been completely overtaken by political forces and there is no economic theory that will tell you what the oil price is going to be. It is a question of "realpolitik".

There are forces pushing the price in both directions and, as a lever to extract insight, we can develop these into two oil price scenarios. Upward pressure leading to Escalating Prices in real terms stems, inter alia, from the influences of those producing countries which have, or face, balance of payments difficulties. Particularly those with limited oil reserve to production ratios will argue most strongly that the price should escalate in real terms to reach the cost of alternative means of obtaining oil or gas (e.g. derived by synthesizing coal) at a not too distant point in the future, say 1990. Higher oil, and hence energy, prices will also render the exploitation of the gas reserves, which most of these producers possess, much more attractive - such projects almost invariably require expensive liquefaction, conversion or pipeline projects to deliver the gas to distant consumers. Then there is the perception that most OECD countries are in a better position to pay for oil; there is a general belief that U.S. imports will continue to increase and of course there can always be further accidents in the Middle Eastern political situation. These and other factors would tend to push the oil price up in real terms, i.e. by considerably more than the rate of global inflation.

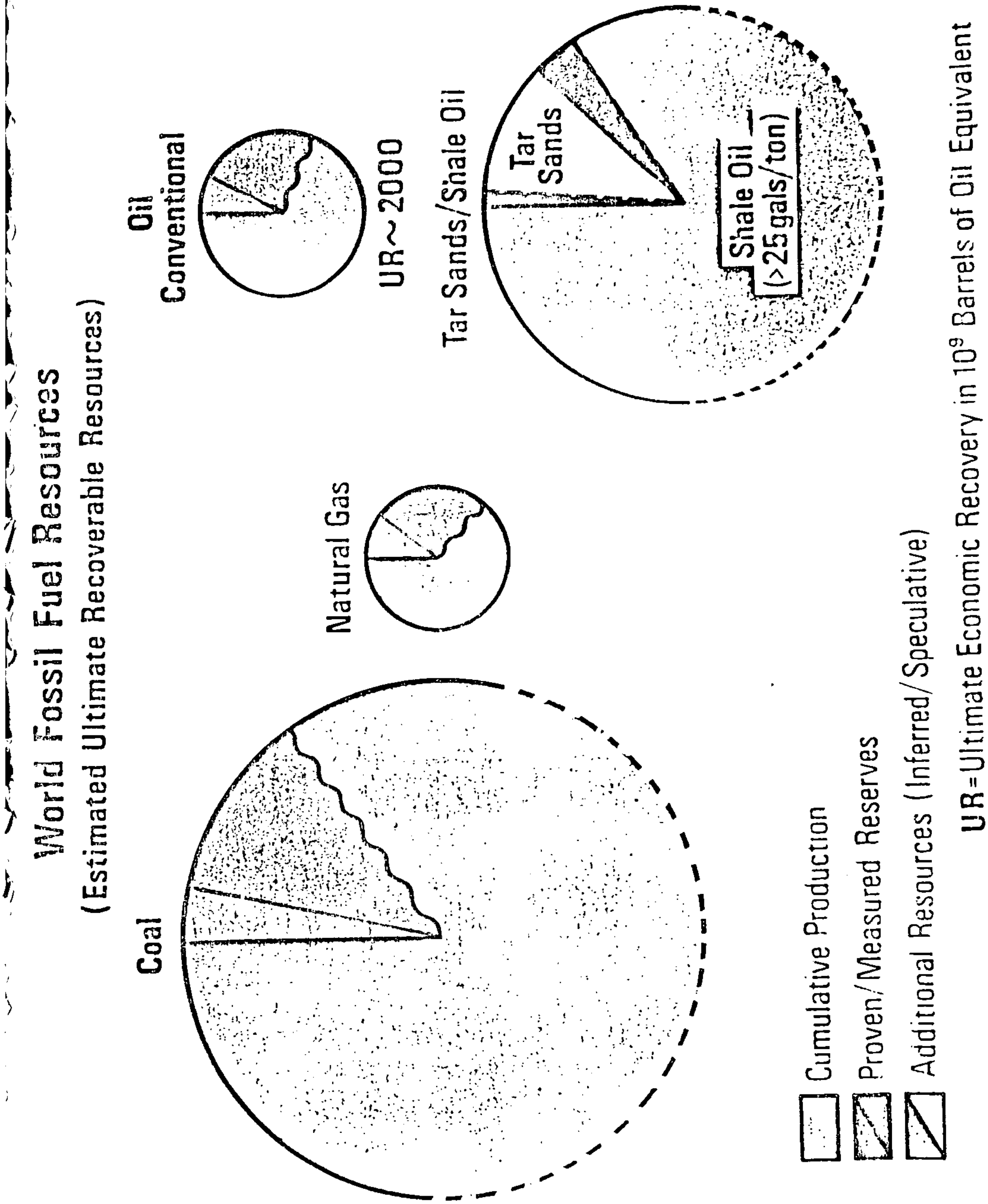
The major forces pushing in the direction of Price Moderation include the concern, particularly expressed by the key producing country, Saudi Arabia, with the economic stability of the West. Other factors such as major new oil discoveries or a belated success for President Carter's energy policy in the USA may also have a part to play. There has been considerable restraint on the part of the producers since 1974 so that it would appear that, at present, we are in a "symbiosis" scenario which could keep prices roughly at today's level - although inflation corrections could either over or under compensate from time to time. Whether this price moderation scenario will prevail is far from certain and depends interalia on future geopolitical developments. Our purpose for developing these contrasting, essentially politically based, archetype price scenarios was as a tool to increase the understanding of the interaction with the other scenario parameters (described above) in the energy supply and demand field.

Exploratory Scenarios for Energy - combining the important variables from the archetype scenarios.

It is clear that the relationship between economic growth and the amount of energy needed to fuel that growth can change in the future, but to get an idea of by how much and in what ways it may change we need to take a detailed look at the markets - the end uses for energy. Similarly, one can use the price scenarios to test for the price sensitivity of demand, but price elasticity is an unreliable concept and we have not found any really worthwhile study that we could use with confidence. No short cut, using for example ex-ante assumptions about changing income and price elasticity of demand for energy, appeared satisfactory. Thus we were driven to the conclusion that a detailed market breakdown coupled with subjective judgement on how each will be affected by higher prices was needed. We had to assess how consumers will react to prices under the different economic scenarios and, more importantly, how governments will react. This is because the private consumer (micro) reaction is often insufficient in view of the national (macro) problem created in balance of payments terms as a result of an oil price increase. For example, an increase of one dollar in the price of a barrel of crude oil can be very serious in balance of payments terms, yet the price of gasoline at the pump, if the crude price increase were spread evenly over the products, would not go up by more than about two cents a gallon.

One way in which governments have already reacted to the earlier price hikes is in the encouragement of energy conservation. Again, the individual consumer is unlikely to use the same criteria for deciding whether or not to implement energy-saving methods. A detailed market breakdown approach turned out to be the only way to manage the assessment of just how much conservation and substitution may be achieved.

Fossil fuel resources, as shown in Figure 1 which looks a bit like planets in the solar system, appear more than adequate but, to come down to earth again, there are economic, societal and geopolitical problems to be overcome if shortages are to be avoided. The warnings of a world rapidly running out of oil are well known and we shall return to these below, but each of the "big three" fossil fuel alternatives also has its problems. There is a great deal of gas around, but most of it is in the wrong place - a long way from the market. Similarly, there is plenty of coal but general aversion to dig it out and reluctance to burn it. The importance of the potential role of tar sand and more particularly, shale oil, in the international energy context has been exaggerated.



n.b. The size of the circles should be taken as indicative only of the order of magnitude of hydrocarbon resources. With the exception of conventional oil, insufficient exploration has been carried out to define the size of the resources base accurately and the technologies for exploiting the reserves are not yet fully developed.

If one looks outside the carbon-based, fossil fuels spectrum nuclear energy is, of course, very important, but generally most unpopular. This is an area where a phantom scenario can be useful. We developed a scenario called Nuclear Disappointment in 1975 to analyse the effects of a major slowdown of such magnitude that at the time it was considered highly unlikely, but would, of course, have a major impact on the world energy situation. Such slowdown in the rate of introduction of nuclear power would have resulted from the lack of consensus over the complex set of technical, economic and socio/political issues surrounding it.

Solar energy and its derivatives, wind, waves, biomass, etc. are superficially attractive because of their abundance, renewable nature and familiarity. The problems arise from their intermittent, diffuse and sometimes unpredictable characteristics. It is too early to say which of the many alternatives will ultimately prove successful and become significant but all are likely to make some contribution depending on local conditions.

At the 1977 World Energy Conference, a Delphi exercise put the ultimately recoverable world crude oil resource base at about 2×10^{12} barrels. About three-quarters of this total is thought to be outside Communist areas (WOCA) and if this was developed at the fastest technically feasible rate, production would peak in the 90's and then start to decline (Figure 2). We also know that the oil-producing countries have many other considerations and they will undoubtedly choose to develop their resources at a slower rate. Analysis of the production profiles for individual countries suggests that the maximum acceptable level of production will be considerably lower than the technical ceiling resulting in a flatter profile of what we call "The Oil Mountain". Nevertheless, there is still significant growth ahead, so that liquid fuels, even from conventional sources, will be with us for many decades to come. The real point, and the reason for the debate about the next energy crunch, is that the demand for oil is likely to be constrained by available supply within the next 20 years, as we shall discuss below.

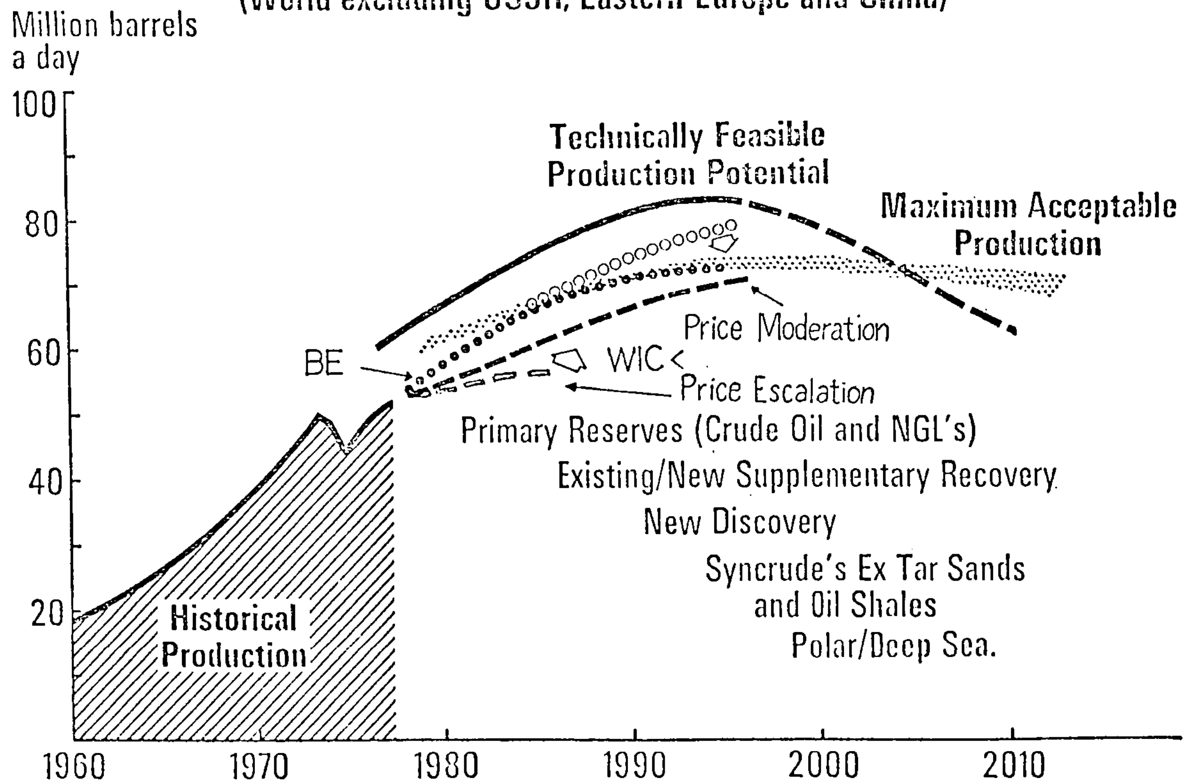
There are critics of the oil industry who think this picture is overly pessimistic and that there may be far more oil to be found than has been assumed. It is certainly true that there are vast reserves of low-grade oil in the form of tar-sands, oil shale etc. (Figure 1) which are only now beginning to be developed and there will undoubtedly be further discoveries of conventional oil as well as improvements in recovery techniques from known reserves. The profile in Figure 2 requires approximately half the oil produced in the year 2000 to come from such "new" sources. This assumes that the huge capital needed can be made available and that the associated technical and environmental problems can be solved. However, the North Sea oil fields have taken over 10 years to bring to present levels and the next oil province might be in even more hostile territories requiring longer to develop. So even if there is a lot more oil, it is not going to change the early part of the production profile very much, but could extend the plateau in Figure 2. The resource base (including unconventional oil) may be adequate but money, technical skills and time may not be.

The Next Oil Crisis - A Mirage?

When we compare the oil demand figures obtained by quantifying the exploratory scenarios with the resource base (Figure 2) some interesting response situations are revealed. For example, we can put a low probability on rapidly escalating oil prices in a low growth world (WIC) because we found that the resulting reduction in oil offtake was such that it would not seem to be in OPEC's interest to follow this route. On the other hand, a low growth world coupled with prices which are approximately constant or rising only slowly in real terms - price moderation - appears at first sight to be a perfectly tenable one. Oil constraints could, in theory, be avoided for the rest of this century, even though the threat of impending crisis might stay with us. This mirage effect, i.e. a crisis which stays on the horizon but recedes as it is approached, could result if low economic growth allows time for some efficiency improvements to be made and for alternatives and new oil to be brought on stream. As an illustration of the physical

The Oil Era — A Perspective

(World excluding USSR, Eastern Europe and China)



effort required by the year 2000, even in this low growth scenario, it is interesting to note that one is talking about some additional:

- 700 Nuclear Power Stations
- 650 Coal Mines
- 60 Liquefied Natural Gas Projects or similar developments
- 7 Oil fields of Nigeria's size plus a roughly equivalent amount of new supplementary recovery from existing reserves.
- 17% Energy conservation relative to 1973 consumption per unit of economic activity

Naturally the above is of an illustrative nature only but it is important to realise that lead times are long (ranging from say 5 to 12 years) and that a considerable effort in related infrastructure will also be required (coal terminals, unit trains, coal burning equipment in power stations, to mention but a few). Figure 3 illustrates what would happen if no action were taken in the field of non-oil energy and the savings assumed in the WIC scenario. Whilst it is physically possible to develop new energy supplies and to achieve the efficiency improvements a prolonged period of low growth would not be the best environment from which the necessary investment decisions could be taken and might give us other, perhaps more serious, difficulties to cope with.

The Energy Outlook - Some Conclusions.

The quantification of the exploratory scenarios was carried out by a detailed end-use analysis of the various energy-using sectors. The analysis has shown that, under all scenarios, future demand for energy is likely to grow more slowly than in the past. A retrospective breakdown of the results shows that there are three major reasons for this: lower economic growth, structural changes and saturation effects in the developed countries and improvements in end-use efficiency. The relative importance of these factors is illustrated with the total energy projections in Figure 4.

Whilst the energy intensive primary and secondary sectors of the industralised countries move towards saturation, relatively faster growth in demand can be expected from the developing countries. Since these countries are not yet so tightly locked into an oil-consuming demand pattern, greater opportunities might exist here for exploiting alternative energy sources, particularly biomass, although it is unreasonable to suggest that they will not require large volumes of liquid fuels, particularly for transport and other preferred uses for energy liquids.

In summary, to return to the question posed in the introduction, as we see it the next energy crunch is either going to be a mirage or it might show itself as a series of mini crises. The future remains uncertain, the outcome remains scenario dependent, but then, as we said, scenarios carry the seeds of their own discontinuity and are therefore likely to pull towards each other. It is a near certainty that a rapid take-off in demand is likely to be followed by a rapid increase in the price of oil which in turn would slow down the world economy and means that the world is in an economic trap - it could be called the "new economic reality".

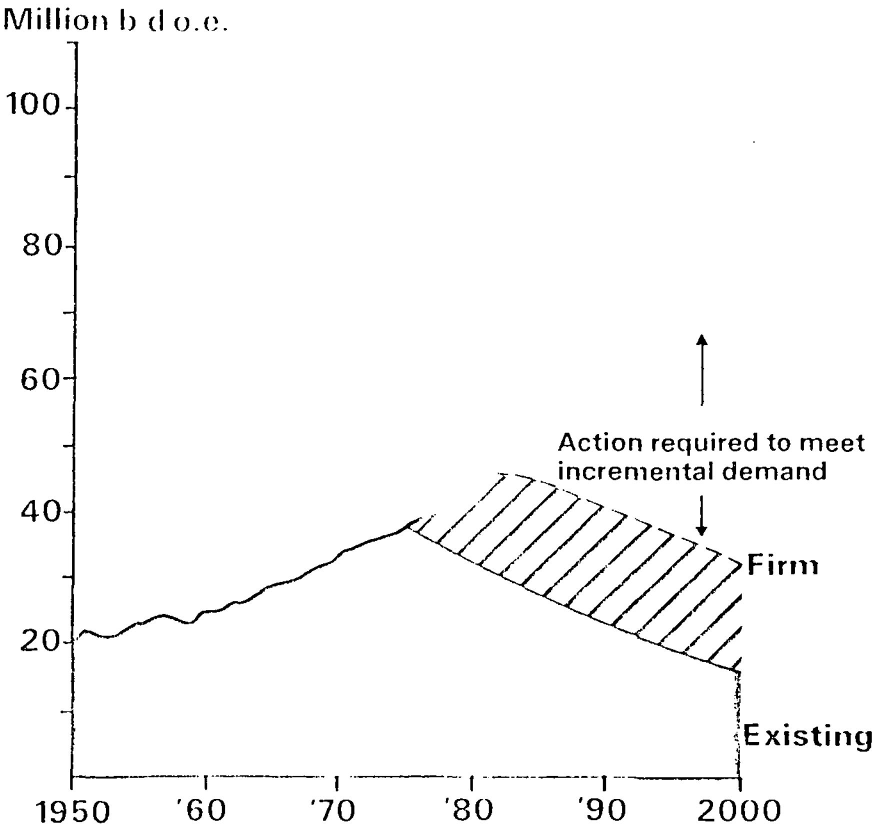
Thus the mirage represents a relatively smooth energy flight under a rather dull and gloomy (economic) sky. The mini crises seem like more of a bumpy ride, i.e. periods of sunshine (economic growth) followed by thunderstorms (oil price increases in real terms). Naturally, a political upset in the Middle East could disturb the delicately balanced oil supply and demand equation at any time. A sudden drop in the supply ceiling as a result of such a geopolitical scenario is hard to plan for but the emergency sharing scheme of the International Energy Agency has been designed to cope with such a contingency. Figure 5 is an attempt to illustrate these scenario conclusions.

To end with Aristotle again, which seems apposite, "knowledge springs from amazement, and amazement comes from an appreciation of contradictions".

November, 1978

FIGURE 3

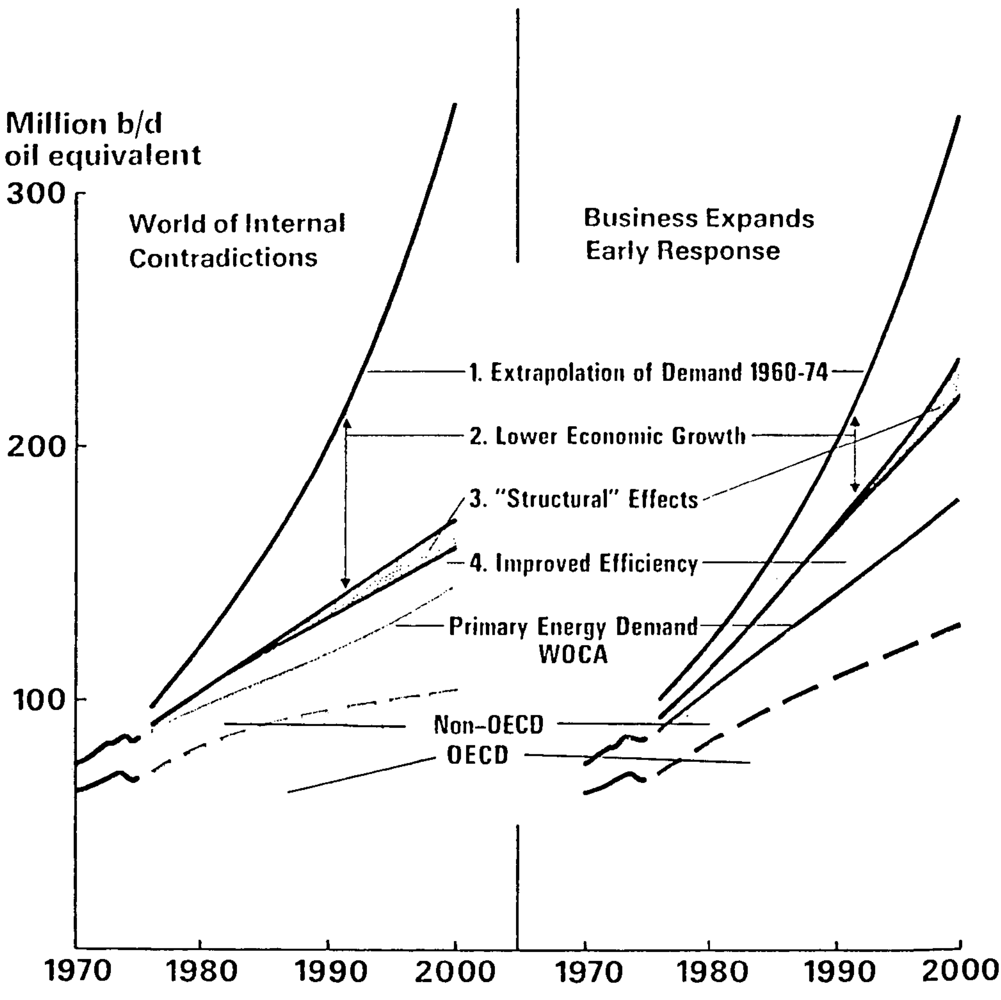
NON-OIL ENERGY PRODUCTION REQUIRED IN WOCA UNDER WIC CONDITIONS (Under BE approximately 66% higher)



n.b. The rate of decline of existing and new firm productive capacity has been calculated on the basis of historic depletion rates of coal and gas resources

FIGURE 4

WOCA PRIMARY ENERGY DEMAND



THE NEXT OIL CRISIS

OIL SUPPLY
OIL DEMAND

MIRAGE

As a result of low economic growth, reaction and pre-emptive action to avoid impending crises, oil supply ceiling remains above demand.

MINI CRISES

Demand hits the oil supply ceiling accompanied by price rise, fall in demand and subsequent repeat of cycle. Crisis made more critical by miscalculation of height of ceiling.

There is also the possibility that the supply ceiling may fall most likely as a result of a political accident.

FIGURE 5

FUTURE WORLD OIL PRICES

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Introduction

This paper summarizes the major findings of an analysis prepared for the Office of Policy and Evaluation, U.S. Department of Energy. The purpose of the study was to delimit a range of world crude oil prices that might occur between now and 1990.[1]

Unlike analyses of most physical systems, analyses of the international energy system are dominated by uncertainty. Two major sources of uncertainty dealt with in this analysis are the future level of OPEC production capacity and future rates of economic growth. Both of these factors affect the balance between supply and demand, hence the price, in the world oil market. In recognition of such uncertainties, the approach taken posits a range of assumptions for each of these factors.

Methodology

The world oil price projections, presented below, were derived from simulations involving four major analysis systems (see Figure 1):

1) The Oil Market Simulation model, which projects world crude oil supply, demand, and prices on a regional basis;

2) The Mid-Term Energy Market model (formerly the Project Independence Evaluation System, or PIES), which simulates domestic energy supply and demand and equilibrium prices for the various types of energy;

3) The International Energy Evaluation System, which is an international counterpart of the Mid-Term Energy Market model; and,

4) The Data Resources (DRI) model of the U.S. economy.

The analysis was initiated by making preliminary estimates of future world oil prices with the Oil Market Simulation (OMS) model. OMS is a reduced form, parametric representation of the world oil market. The model calculates a price of oil that will balance total world supplies with total world demands. These preliminary estimates indicated that even with moderate rates of economic growth, world oil prices might double, or even triple, by 1990.

The initial estimates were preliminary in the sense that they were derived using a calibration of the OMS model which was consistent with world oil price levels of around $15 per barrel. In order to recalibrate elasticities in the OMS model to be consistent with much higher world oil prices, it was necessary to use the other three models to analyze the adjustments of energy supply and demand and economic activity to high oil price levels.

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1 The views and interpretations expressed in this paper are those of the author and do not necessarily reflect a position of the Department of Energy. For a more complete presentation of this analysis, see (1).

To gain further insight into this problem, it may be useful to follow the adjustments which occur in the OMS model if world oil supply and demand are not in equilibrium. When demand exceeds supply, consumers bid up the price of oil. As a result, the following three adjustments are set in motion:

- An increase in the price of oil encourages an increase in the production of additional oil supplies;

- An increase in the price of oil causes the quantity of oil demanded to decline and the demand for alternative energy forms to increase; and,

- Increases in the price of oil adversely affect the rate of inflation and trade balance in countries dependent on oil imports which reduce their rate of economic growth. This decline in economic activity reduces both their total demand for energy and their demand for oil.

The magnitude and net effect of these adjustments vary not only from one region to another, but according to the magnitude and timing of the price increase. Thus, the Mid-Term Energy Market model and the DRI macroeconomic model were used to analyze the adjustments within the domestic energy system and the domestic economy to alternative world oil price trajectories. The International Energy Evaluation System was employed in a similar fashion to analyze the adjustment of foreign energy systems. These results provided the information necessary to recalibrate the OMS model.

Results

Two ranges of future world oil prices were projected with the OMS model based on two economic growth scenarios. Table 1 shows the range of economic growth rates used to define the optimistic and pessimistic growth scenarios. The optimistic growth rates are consistent with those reported in the Energy Information Administration's (EIA's) Annual Report to Congress (see 2, page 67). The pessimistic growth rates were arbitrarily assumed to be one percentage point lower.

For each economic growth scenario, ranges of world oil prices were determined by constraining the level of OPEC production capacity according to the optimistic and pessimistic estimates shown in Table 2. These estimates are also consistent with data reported in EIA's Annual Report, see (2, page 81), and suggest that development of Saudi Arabia's production potential presents the major uncertainty in this area.

Figure 2 illustrates the range of world oil prices projected for each economic growth scenario. In this figure and throughout this discussion, oil prices are expressed in 1978 dollars per barrel delivered to the East Coast of the United States. The upper end of each price range corresponds to the pessimistic estimate of OPEC capacity, 36.5 million barrels per day in 1990, whereas the lower end corresponds to the more optimistic estimate of 43.5 million barrels per day.

As shown in Table 3, the real price of oil could begin to rise as early as 1982 and reach the $26-37 per barrel by 1990, if the optimistic growth scenario becomes a reality. Realization of the lower economic growth estimates could delay any real price increases until the 1985-1988 period with prices reaching $16-21 per barrel range by 1990.

Conclusion

Based on the findings of this analysis, it is not unlikely the recent leveling off of real oil prices will come to an end in the next decade. Exactly when oil prices could begin to rise in real terms and to what levels is highly uncertain. It must also be noted that although such increases are likely, they are not inevitable. A number of events, such as extensive energy conservation, accelerated development of new energy sources, or the adoption of aggressive energy policies in the United States and elsewhere could significantl delay another round of escalation in world oil prices. The potential effects of these and other factors are the subject of an ongoing analysis within the Energy Information Administration.

References

(1) Energy Information Administration, An Evaluation of Future World Oil Prices, Analysis Memorandum AM/IA-78-05, June 1978.

(2) Energy Information Administration, Annual Report to Congress, Volume II, DOE/EIA-003612, Washington, D.C., April 1978.

Table 1

Economic Growth Assumptions
(Average Annual Rates)

Country or Region	1975-1985		1985-1990	
	Optimistic	Pessimistic	Optimistic	Pessimistic
United States	4.2	3.2	3.1	2.1
Canada	4.2	3.2	3.1	2.1
Japan	5.6	4.6	5.6	4.6
OECD Europe	3.6	2.6	3.8	2.8
Australia/New Zealand	4.1	3.1	4.5	3.5
Developing Countries	6.6	5.6	6.2	5.2
OPEC	5.5	4.5	4.4	3.4

Table 2

Range of OPEC Production Capacities
(Millions of barrels per day)

Country	1985		1990	
	Optimistic	Pessimistic	Optimistic	Pessimistic
Saudi Arabia	12.0	10.0	17.0	12.0
Kuwait	3.0	3.0	4.3	3.0
United Arab Emirates	3.0	3.0	3.2	2.5
Other Arab OPEC	8.0	8.0	8.3	8.3
Other OPEC	12.8	12.8	10.7	10.7
Total OPEC	38.8	36.8	43.5	36.5

Table 3

Summary of World Oil Price Analysis

Optimistic Growth	Year of Initial Price Increase	World Oil Price[1] 1985	1990
Optimistic Capacity	1982	19.00	26.00
Pessimistic Capacity	1982	21.00	37.00
Pessimistic Growth			
Optimistic Capacity	1988	14.50	16.00
Pessimistic Capacity	1985	15.00	21.00

1 Prices are stated in 1978 dollars per barrel, C.I.F. East Coast of the United States.

Figure 1

Overview of Analysis Methodology

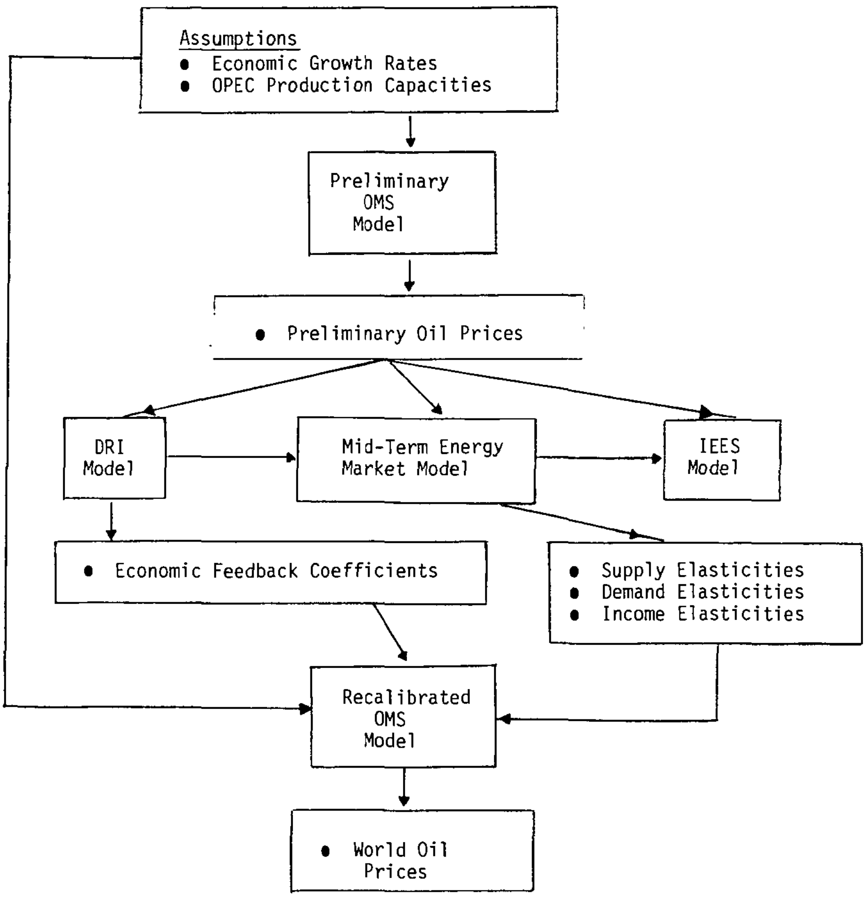
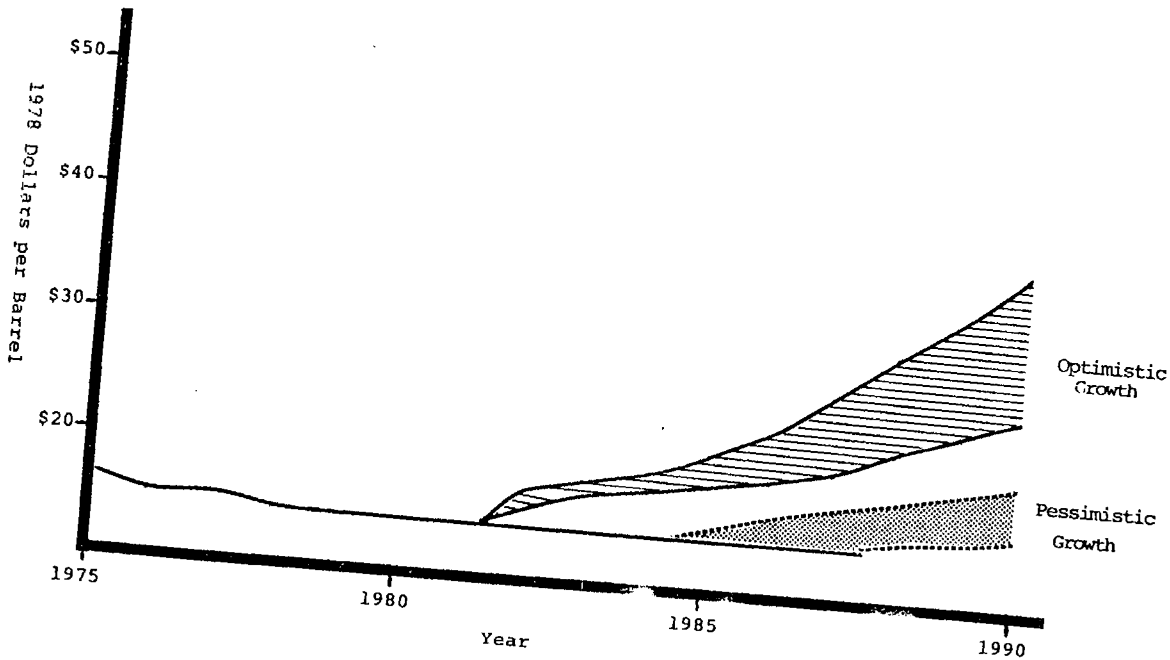


Figure 2

WORLD OIL PRICE PROJECTIONS



ABSTRACT - FUTURE OF NATURAL GAS, G. J. MacDonald. The MITRE Corporation, 1820 Dolley Madison Boulevard, McLean, Virginia 22102.

Some fraction of natural gas found in deposits not associated with petroleum may have an abiogenic origin with the gas produced by igneous activity or as a result of the outgassing of primeval hydrocarbons accumulated during the formation of the earth. Evidence for an abiogenic origin include the ratios of the stable isotopes of carbon and hydrogen in methane, temperatures deduced from isotopic ratios of coexisting methane and carbon dioxide and methane and water, the bulk chemical composition of the gas deposits, the age and geologic setting of the deposits, the presence of methane in volcanic emissions and hydrothermal gases and the accumulation of large quantities of methane in the cold waters of recent lakes in the volcanic regions of the East African Rift Zone. The possible existence of abiogenic methane could greatly alter estimates of the remaining economically recoverable natural gas. In the United States, major structural features that could trap gas of whatever origin have probably been discovered. However, difficult to discover, stratigraphic traps are known to exist and exploration for these would be aided by knowledge of the source of the methane. Abiogenic methane could be expected to accumulate, for example, in the vicinity of regions of igneous activity or near deep faults that penetrate basement rocks but that do not reach the surface. Such regions have not been favored in conventional exploration of hydrocarbons.

THE POTENTIAL CONTRIBUTION OF COAL TO WORLD ENERGY FUTURES

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Introduction - IEA Coal Research

Since IEA Coal Research exists precisely to examine and develop the subject given in the title, this paper will mainly be devoted to describing the activities of that body.

The International Energy Agency was formed in 1974 by O.E.C.D. countries, in response to problems arising from discontinuities in the supply and price of oil at that time. One objective of the IEA was to encourage alternative to oil, especially through Research and Development programmes of a collaborative nature. The potential energy alternatives were divided into discrete technical fields; the U.K. was nominated the lead country for coal. Certain projects were initally proposed in 1975 and were each accepted by a sufficent number of countries to make a viable set of programmes. The principles behind these inital proposals have proved durable. The early progress of the work has already provided substantial new information, both technical and also about the methods by which countries can work together. This experience, assisted by the fact that IEA Coal Research is detached from immediate responsibilities within the coal industry and therefore in a more objective position, is allowing a clearer picture of the future world potential for coal to be developed progressively.

The IEA provide no central funds for the R & D groups and there were initally no administravtive procedures of finacial conventions. The only asset at the beginning was that most of the countries who had joined IEA through their mutual interest in the problems of oil dependance also perceived that coal provided a means of alleviating those problems and were willing to send representatives, generally without madates however, to the early meetings of a Coal Working Group.

From the outset it seemed essential that the Working Group should sponsor one major "hardware" project. However, it also seemed that several questions needed to be answered if the IEA countries were to be influenced further in the direction of coal, both for long-term resource planning and for short and medium term R & D programming. It was proposed that this should be done by the establishment of "Service Projects" or office studies. The service projects and the questions they were designed to answer are:

(a) Resources and Reserves. Is the coal really there? In circumstances making economic recovery plausible? Can output be greatly increased and the product made more widely available?

(b) Mining Technology Clearing House. Is the technology for recovering coal adequate? Is the technology capable of developing in ways which will meet increasing stringencies in human and environmental

(c) Technical Information Service. Is the coal industry fragmented and disunited or is it capable of co-operation in order to maximize the impact of developing technology on an international scale?

(d) Economic Assessemt Service. Will coal be economically competitive? How, when and where.

The hardware project chosen was Pressurised Fluidised Bed Combustion (PFB) at a total programme cost now expected to be in excess of $40m. The annual cost of the Service projects described above is of the order of $2m. An organisation, referred to here as IEA Coal Research, has been set up to carry out this work, to make further proposals and to exploit the achievements for policy guidance.

Resources and Reserves of Coal

The World Energy Conference (WEC) is the best current source of information on energy resources, since the different sources are discussed both separately in relation to each other and because such a wide spectum of countries participate in a constructive manner. Thus, whatever uncertainties there may be in the data, the results and conclusions have a very important political validity.

The WEC Coal Resources Study was carried out by Peters and Schilling of Bergbau-Forschug, Germany; their results, which were not in any way challenged, are summarized in Table 1; Fig. 1 shows the planned coal production. "Technically and Economically Recoverable Reserves" are those which could be produced using current technology at a cost which would be economic at current prices. These reserves, defined on this stringent basis, represent only 6% of the total resource base but would nonetheless last for 250 years at current outputs. Only a small shift in prices, technology or in accuracy of exploration would be needed to transform a substantially further proportion of resources into the economic reserves category. Furthermore, the resource base itself is still expanding, as a result of increasing interest. Fig. 1 is based on output figures assessed mainly from plans stated by various countries. Line 1, which shows the annual output rising from 2.6b. tones to about 7.0 in 2020, could be achieved even if output were restricted to an operationally conservative level based only on present reserves. If the reserves were doubled, say by a small change in the economic base, line 3 reaching nearly 9.0b. could be achieved and sustained for a very long time. Thus, there can be little real doubt about the feasibility of a very large increase in coal production, so far as technical reserves are concerned. It should be noted that the increase, about 3% per year, follows the trend established over many decades. Producing countries expect to have about 10% of their output available for export. At some time, therefore, perhaps within two or three decades, coal will probably re-assume from oil its former leadership, both as a source of energy and as a form of traded energy.

IEA Coal Research, while welcoming these figures and not doubting their implications, felt that more information would be needed in support of this "second coming" of coal, especially in view of the very important decisions on which would be necessary for exploitation. It is noteworthy that the World Energy Conference is itself becoming more interested in improving coal assessment methods and that the United Nations is arranging a meeting early in 1979 to produce a common classification system as a prerequisite to a world assessment.

IEA Coal Research is linked to the data bank of the U.S. Geological Survey. Its immediate objectives are, first to compare different assessment systems and nomenclatures used in various countries, leading to a common sythesis, and, second to provide a preliminary catalogue of all known World coalfields. The first of these tasks is virtually complete and the second, covering more than 3000 deposits, should be completed early in 1979. It is already clear that there is no reason to beleive that the WEC estimates are over-stated in total.

Aggregations compiled from disparate components do not form a suitable basis for national and international policy decisions, whether these are for investments in mining and utilisation within a single country or for multi-national planning which depends on trading, implying harmonious developments in the exporting and importing countries. The assessment of deposits requires study of the following factors, some of which are interlinked of course:

(i) Existance: how much coal in total exists in the gound;

(ii) Coal type; what sort of coal exists and what are its potential uses,

(iii) Extractability: what proportion of the coal in the ground could be brought to the surface;

(iv) Usefulness: what proportion of coal brought to the surface could be used;

(v) Potential Cost: of bringing the coal to the ground;

(vi) Potential Proceeds: of the coal so recovered;

(vii) Accessibility: whether the coal is immediately accessible or whether some obstacle has to be removed first;

A proposed classification form based on these factors is given in Appendix 1. The definitions of accessibility are:

(i) accessed by current working, or those for whose development capital expenditure has been committed;

(ii) a) accessible to current technology within existing legal and environmental restraints and with existing infrastructure;

and,

b) coal which remains accessible in previously worked but abandoned areas;

(iii) dependant for their exploitation on the provision of infrastructure (transport, housing, etc.);

(iv) accessible only after some <u>defined</u> change in circumstances such as

a) removal of environmental prohibitions;

b) removal of other legal restraints (e.g.licenses);

c) the development of a new technology (e.g. underground gasification);

In the diagram the ratio of costs to proceeds, C/P, is used to provide a measure of economic viability and certain boundaries, at ratios of 1, 2, and 4, are suggested. The setting of these boundaries and the rules for the calculating C and P are difficult matters, which affect the categorisation of "reserves". These reserves may be thought of as being column A of the diagram, at accessibilities 1 down to 3 (including costs of infrastructure). It will be apparent that less knowledge is needed for the lower parts of the diagram.

Some conclusions which may be derived from these early attemps to develop assessment and classification system are:

1. In assessing potential coal recovery it is essential to consider the deposit as a whole and to understand the effect of progressive removal of seams.

2. There is little point in attempting to assess total coal in country or

in a particular deposit beyond the point of ensuring adequate supplies for the next 50 years.

3. It is desirable to establish the physical parameters of deposits to enable potentially recoverable coal to be related to current technology; it is also necessary to ensure that technical research and development is appropriate to its future context.

4. Any new modified system has to be based on the fact that, for the most part, operators generate the information they need and are only interested in wider assessments which benefit their activity. These wider assessments should help to steer the operator as well as national and international policy.

5. Coal is a wating asset and continuation of the policy of taking first the best of what is left is only valid if the second best can or is likely to be recovered later, and if coal to be abandoned is adequately identified.

Mining Technology

This is not the place to explain detailed mining developments but it is important to emphasize the urgency now attached to this subject throughout the world. Substantial success has in fact already been achieved in practice but this is often over-looked, possibly due to adverse publicity over industrial relations. Coal mining technology is likely to be largely transformed over the next couple of decades, probably not through any revolutionary discovery but through an evolutionary procedure using information now available or well advanced in development and, most important, through investment. All this should make coal a more reliable energy source with more predictable costs.

This confidence has been enhanced by the studies so far carried out by the IEA Mining Technology Clearing House (MTCH). Mining research and development has expanded very rapidly recently - there are several time as many scientists and engineers engaged now compared with ten years ago. MTCH has catalogued over 2000 R & D projects in the eight co-operating countries alone and from this has developed critiques and overviews which should help in rationalisation and collaboration as well as suggesting lines for future emphasis. MTCH has boundaries with other IEA Coal Research work, for obvious being with Resources and Reserves. An example is that, since coal is a wasting asset, percentage recovery is becoming an increasingly important measure of efficiency. Monitoring recovery performance is a key function especially in relating recovery to the needs of economy and conservaion now under the impact of changing extraction technology.

Mining technology is closely linked to transport and utilisation. In this connection, particular interest has been focussed on hydraulic mining and transport. This subject, and several others identified through the surveys are currently under consideration as possible co-operative "hardware" projects in mining technology.

Technical Information

A key function of the Technical Information Service (TIS) is the production of Coal Abstracts, a service which was previously greatly missed. A perusal of this journal, incidentally, quickly gives a clear impression of the tremendous current interest and activity in coal. All information is of course computerized, with international links. Besides the standard information service, including the preparation of a Coal Thesaurus, TIS provides, for organisations in member countries, an Enquiry Service and a Selective Dissemination of Information Service. In addition, a series of Special

Technical Reviews of key topics is being prepared; these will review all the available literature on the topic and provide constructive summaries and appraisals, suitable for non-experts but useful also to experts because of the comprehensiveness of the sources used. Reviews already issued include:

a) Underground Transport in Coal Mines.

b) Carbon Dioxide and the "Greenhouse Effect".

c) Combustion of Low Grade Coal.

Topics under preparation or consideration include:

a) Surface Transport of Coal.

b) Loading and off-loading of Coal to/from Ships/Rail.

c) Hot Gas Cleanup.

d) Combustion of coal with control of Particulates and NOx.

e) Methane Prediction in Coal Mines.

f) Monitoring of Coal Quality.

g) Conversion of Oil-fired Plants to Coal firing.

H) Materials Problems During High Temperture Coal Conversion.

i) High Temperature Gas Turbine.

The Review on Carbon Dioxide has been received with particular interest and this applies in general to other matters relating to environmental impact. It is believed that these questions are now of sufficient importance to merit more direct and original investigation than appropriate for TIS and proposals are being made for a separate Service to be established; this might benefit from association with other organisations.

Economic Assessment

This must be the central feature of any organisation studying the future contribution of coal. Even environmental factors have economic impact. The Economic Assessment Service (EAS) considers the cost and availability of coal, its transport and its utilisation, in relation of course to alternatives and different timescales, under the following main headings:

a) Economic and Technical Criteria for Coal Utilisation Plant.

b) Technical and Economic Factors Associated with Effluent Disposal.

c) Cost and Availability of Coal.

d) Transport of Coal.

e) Coal Conversion Economics.

f) Costs of Coal Conversion Plant.

g) Fuel Costs and Demand for Coal.

h) Relative Costs of Coal Based Energy.

Although the conversion of coal into gases and liquids, including feedstocks, is of great importance, combustion is likely to remain the most important outlet for sometime. Accordingly, under (h) above, attention has so far been focussed on:

(i) The competitive position of coal in electricity generation .

(ii) The competitive position of coal in direct heating for industry.

(iii) The competitive merits of gas vs. electricity vs. direct coal heating in industry.

Item (i) is particular importance, especially in view of discussion surrounding the future of nuclear power. In economic comparisons between coal and nuclear power. there remain substaintial uncertainties and areas reflecting judgement or policies, In the case of nuclear power, reports of capital cost vary considerably and fuel costs are also uncertain partly due to uranium resources but also because the fuel cycle has not been closed. In the case of coal, flue-gas desulphurisation (FGD), if needed, may amount to 20% of total plant costs. Finally, interst rates and projections of future real costs are dominant but subjective items and results also depend crucially on load factor. The resulting comparisons are therefore quite complicated and the various nuclear and coal cases overlap substantially. In the U.K., however, at present it is considered that if a "medium cost" nuclear case is compared with coal based generation *without* FGD (not required at present or projected) the breakeven price of coal would be £1.2/GJ. If 100% FGD were required, the breakeven price would be £0.81/GJ (current British price £0.95). Another comparison, on British data, makes the assumption that nuclear capital costs will stabilise either at present levels ("medium") or at 25% higher ("high") and clculates the maximum <u>real</u> annual coal cost inflation which could be suffered for coal to remain competitive. The results are:

100%FGD/medium nuclear	Not competitive
100%FGD/high nuclear	2.2%
No FGD/medium nuclear	2.5%
No FGD/high nuclear	5.3%

In the U.K. such annual rates of coal costs increase do not seem credible, in the light of current investment, nor can 100% FGD be regarded as at all likely. Each country will have its own attitude to FGD but the effect that this has had on the breakeven coal cost - a reduction by one-third, say - should be borne in mind when assessing any benefits from sulphur suppression especially to very low levels.

These studies have now also considered the economic impact of the introduction of Fast Breeder Reactors. At this stage it is very difficult to see how the FBR can be justified even in comparison with thermal reactors without making assumptions which are either incredible with regard to the growth of nuclear electricity or which make thermal reactors themselves much less attractive.

Perhaps more directly relevant, at least to IEA Coal Research, a preliminary assessment has been made of the comparison between conventional coal generating costs (with FGD) and fluidised combustors both atmospheric (AFB) and pressurized (PFB). The first results, expected as percentage savings in electricity cost are:

PERCENTAGE SAVINGS IN ELECTRICITY COSTS

Coal Price	High Sulphur		Low Sulphur	
	AFB	PFB	AFB	PFB
\$1/GJ	13-15%	7-8%	<3%	3-4%
\$2/GJ	12-14%	9%	<3%	4-5%
\$3/GJ	11-13%	10%	<3%	4-6%
OVERALL	11-15%	7-10%	<3%	3-6%

The main "hardware" project of IEA Coal Research is an experimental unit based on PFB. This project has been described eleswhere. It is expected to be commissioned in the early Spring of 1979 and has initially a two year programme of work mainly on combustion factors, with particular attention to the quality of off-gases for direct use in turbines. Proposals for adding a gas turbine, which would effectively convert the test equipment into a pilot plant, are being considered. The earlist that this could be completed is about the end of 1981 which probably corresponds to the need to complete the basic combustion programme first.

The preliminary economic assessment quoted above, whilst showing reasonable potential for fluidised combustion power generation where FGD must be practiced on high sulphur coals do not show much saving with low sulphur or any advantage for PFB over AFB. This obviously calls for collaboration between the technical and economic studies. Apart from better engineering to reduce capital costs, from which the more complex system should benefit most, consideration will have to be given to other ways in which the competitiveness of PFB can be increased initally as a guide to further experimentation. In the calculations above, PFB, is taken as having only 3 percentage points advantage in thermal effeciency over AFB. Clearly if this can be increased, so will the economic benefit and this would be compounded by fuel price increase. Thus, great emphasis must be put on thermal efficiency, which is most likely to be increased by higher temperatures. In addition, the system itself will nedd further examination, including continuous reconsideration of the duty of PFB, in conjunction with other processes and within the broader study of energy flows.

Similar studies to those described above on combustion will be required on other coal conversion processess and these are in hand by EAS, as are combinations of processes (Coalplexes). Coalplexes, intermediates may be transferred and more than one product is available. It is likely that hydrogen costs will be a key factor in economic studies in the future, not only for coal but for the whole family of fossil fuels. This has led to suggestions of a sequential use of hydrocarbons and this may result in separation procedures as an initial step in coal processing, in order to recover fractions having a higher hydrogen content or small molecular size; the residues could be gasified and/or combusted. Obviously, the development of more elegant utilisation systems for coal will require re-optimisation of quality requirement for mining and preparation of transport methods.

Conclusions and Predictions

The resources of coal are very large indeed, so large that the rate at which the world decides to exploit them is a matter of choice based on economics and investment policies, rather than resource constraints. It seems highly probable that output will be increased several-fold over the next few decades, without the danger of a sharp peak followed by a rapid decline which may occur in the case of oil and gas. Coal is fairly well distributed and is readily transportable and storable, so that trading should become much more important in the wake of oil. Practically all countries should therefore seriously consider their policies for coal and most would benefit by doing so through international collaboration. Countries possessing ample coal may need capital to make large investments in developing these resources; potential importers need to invest in handling and utilisation equipment. Coal may be transported as such or converted into coal products in the producing countries and the merits the alternatives need careful consideration on a case-by-case basis. Partnerships between producers and users should therefore be formed at an early stage and a wide range of options involving current and future processes considered.

The understanding of how to get and how to use coal is developing progressively. Within individual countries a new approach to mining and distribution is necessary. Hydraulic mining and transport, for example could help to separate mining from its traditional environmental impact and might also provide flexibility in the location of energy conversion and comsumption centres. Utilisation patterns will certainly change sequentially, in timescales which may be consistent both with the peaking and run-down of other hydrocarbons and also sequence from low to high value uses will be based on adding more hydrogen which will increasingly be derived form coal.

The development and economic progress of new coal conversion processes will call for re-optimisation of all the stages in getting, preparing and using coal including schemes where the more valuable portions are removed before the residue is used for the crude outlets. Envisaging the complex nature of the coal industry in the next century is perhaps more difficult than trying to see the modern petroleum industry from its origons at Titusville might have been. Still, it should be attempted now and progressively updated.

For the present however the most important outlet for coal is combustion. For electricity generation coal is likely to continue to compete successfully and will become very important for direct heating. Fluidised Combustion, in various forms, will be the main contributing technological factor.

All countries will be affected by the optimal use of coal will all benefit from the extension of collaborative arrangements. IEA Coal Research has demonstrated some ways in which this collaboration might progress.

Hard Coal (bituminous coal and anthracite)

Continent	Geological resources in 10^6 t. c. e.	percentage	Technically and economically recoverable reserves in 10^6 t. c. e.	percentage
Africa	172 714	2	34 033	7
America	1 308 541	17	126 839	26
Asia	5 494 025	71	219 226	44
Australia	213 890	3	18 164	4
Europe	535 664	7	94 210	19
Total	7 724 834	100	492 472	100

Brown Coal (subbituminous coal and lignite)

Continent	Geological resources in 10^6 t. c. e.	percentage	Technically and economically recoverable reserves in 10^6 t. c. e.	percentage
Africa	190	--	90	--
America	1 408 838	59	71 081	49
Asia	887 127	37	29 626	21
Australia	49 034	2	9 333	7
Europe	55 241	2	33 762	23
Total	2 400 430	100	143 992	100

Total

Hard Coal	7 724 834	76	492 472	77
Brown Coal	2 400 430	24	143 992	23
Gesamt	10 125 264	100	636 364	100

Table 1 : The Distribution of World Coal Resources, grouped by Continents

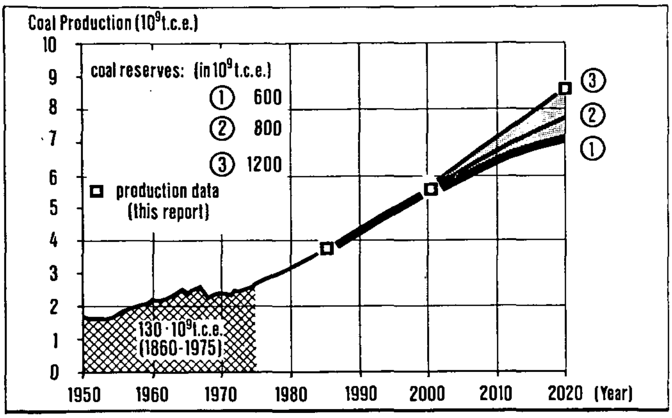

Fig. 1 : Future Trend in World Coal Production, based on Different Amounts of Coal Reserves

Appendix 1

MAIN CLASSIFICATION

Date of assessment.......

Coal type........... Location................

Decreasing accessibility ↓ Decreasing economic viability →

tonnes x 10^9

Access Category		Assurance Bracket	Economic Category			
			Coal recoverable at:-			D Coal in place
			A C/P ≤ 1	B C/P ≤ 2	C C/P ≤ 4	
1	1. Accessed	most likely maximum minimum				
2	2. Accessible	most likely maximum minimum				
(a)	Total of 1 & 2	most likely maximum minimum				
3	Accessible after provision of infrastructure	most likely maximum minimum				
(b)	Total of 1, 2 and 3	most likely maximum minimum				
4	Accessible subject to other conditions	most likely maximum minimum				
(c)	Total of 1-4	most likely maximum minimum				
5	Inaccessible	most likely maximum minimum				
(d)	Total 1-5	most likely maximum minimum				

Notes:
1. Economic category A is included within B, B within C and so on.
2. Access categories 1 to 5 are separate from one another and do not include one another.
3. The most usual view of 'reserves' - currently economic accessible coal - is represented in Column A, line (a).
4. Coal in place (Column D) may be limited by excluding coal below a a given thickness or depth, varying from country to country. Such limits will be recorded.

JAPANESE ENERGY OUTLOOK AND INTERNATIONAL COOPERATION

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1. Formation of a High-Energy-Consumption Type Economy

It was after the 1960s that the Japanese economy has become that of high-energy-consumption type. The volume of energy consumed during fifteen years up to 1975 far exceeded the volume consumed ever since the beginning of Meiji Era up to 1960. Average annual per capita energy consumption during the recent five years was about 4.5 times that in the period prior to World War II. The transition of the economy to that of high-energy-consumption type coincided with the shift of energy from hydraulic power and coal to petroleum.

Energy consumption grew during the 1960s by an average annual rate of 13%. In Japan technological innovation bloomed in the 1960s. Materials industry such as metals, chemicals, and synthetic textile developed modern mass production systems. And mass assemblying industry such as automobiles and home use electric appliances developed based on the supply of such materials of a good quality for a low price . Consumers durables rapidly saturated homes, and "throwaway" became a common place. Equipment investments increased in industries, and public investments such as roads and highways and ports and harbors also increased. Heavy and chemical industries was much developed, and the economy grew rapidly. An "affluent society of mass production and mass consumption" was formed.

2. Fragility of Energy Supply Base

This "affluent society" is a grand house built on petroleum. Demand for primary energy expanded from the 95 million tons of 1960 to 284 million tons in 1970, and 87% of this increase was supplied by petroleum--almost all imported.

When rapid economy growth began in Japan under technological innovation, rapid increase in petroleum production began in Middle East and Africa. International oil companies raced to increase their market shares and reduce the price of petroleum. OECD could not stop it. The world entered into an oil age. The Japanese economy took full advantage of low-priced petroleum suply. But since the beginning of 1970, the international petroleum situation largely changed. Due to Worldwide expansion in petroleum consumption, the demand and supply of petroleum became tight. The position of OPEC was strengthened, and nationalism rose in oil producing countries where the government intensified controls over their petroleum resources. The era of abundant supply of low-priced oil ended, and the world entered the era of high-priced oil.

3. Change in Growth Pattern and The Decline of Energy Elasticity

At the time the world's oil situation changed, the pattern of Japanese economic growth also changed. Since the beginning of the 1970s increase in private equipment investments slowed down because new technology had been introduced into all sectors, environmental destruction had advanced, and the spread of consumers durables slowed down. Metals, chemicals, and other materials production increase slowed down. Such growth pattern change and industrial structure change naturally affected energy consumption. And this tendency was accelerated by the energy price hike and economic stagnation since the oil crisis of the fall of 1973.

A review of energy consumption in relation to GNP indicates that consumption in the industrial purposes had been on the decline while that for household purposes had consistently in creased. Energy consumption for transportation purposes remained little changed since the 1960s. The ratio of household consumption of energy to total consumption was still too small to cover in full the decline in industrial consumption, and energy elasticity to GNP had declined.

4. Future Economic Growth and Energy Consumption

Japanese economy will need to grow by about 6% annually in order to sustain full employment, to accomplish fuller social security, and to develop public facilities. And it is believed that the economy would have that much of potentiality provided that there would be no limit on energy supply. It will be 0.9 in consideration of the elasticity during the period from 1970 through 1976, future recovery of equipment investment rate, and the estimate (0.91) under the New Energy Plan of the Government of West Germany, energy demand under economic growth of about 6% will be 660 million KL in 1985. Conservation of energy can depress the demand to less than the indicated. If 5.5% saving is achieved, demand will be 625 million KL in 1985.

5. Continuously High Future Reliance on Petroleum

Policy for stable energy supply is conceived of in the direction as indicated below.

(1) Domestic resources will be exploited as much as possible.
(2) Development of nuclear power generation will be propelled at social consensus, while making efforts to increase its safety and reliability.
(3) Of imported energy, the utilization of natural gas and coal will be expanded.
(4) While reducing reliance on imported petroleum through the above listed measures, petroleum supply source will be deversified.

The possibility of Japan's domestic resources exploitation is low. Also, the development of nuclear power generation will proceed only slowly due to citizens' movement against nuclear power generation. The government inevitably will lower the previous development target of 49,000 MWe by 1985 to 26,000 MWe. Even if smooth operation of these nuclear power plants is assumed, the total volume of energy supplied from domestic sources, including such plants, will be only about 84 million KL (in terms of petroleum).

Therefore, an overwhelming portion of energy demand will have to depend on imports. In order to diversify imported energy, the potential was estimated under the policy that the importation of natural gas (liquidified) and coal will be increased as much as possible.

The total potential supply volume of energies other than petroleum, as discussed in the above, is only 195 million KL (in terms of petroleum), and the balance must depend on imported petroleum. Assuming that 5.5% conservation will be accomplished by 1985, said energy demand will be 625 million KL, which means that 430 million KL (or from 7.4 million barrels per day) of petroleum will have to be imported.

If economic growth of about 6% is to be sustained, continuously greater amounts of petroleum will have to be imported. Even if the source is diversified to China and Indonesia, and overwhelmingly large portion of import will have to come from Middle East. In view of the political instability in Middle East, the energy base of the Japanese economy is extremely fragile.

6. World Limit to Oil Production

Petroleum experts believe that the petroleum production of the world (excluding communist countries) will reach its peak in the first half of the 1990s and will subsequently continue to decline. Main reasons for this are deterioration of discovery rate (new Petroleum fields) and the preservation policy of oil producing country governments.

Discover rate will drop due to the worsening of natural conditions, rise in development costs, decline in investment potentials of international oil companies and national companies. Gap between increasing production volume and discovery rate will open in the shape of scissors, Long Term Projection of Energy Demand and Supply Balance

Fiscal Year	(Unit)	F.Y. 1975 Actual		F.Y. 1985 Projection	
Demand of Energy before Conservation	M.KL			660	
% of Reduction of Energy Demand by Conservation	%			5.5	
Energy Demand after Conservation	M.KL	390		625	
Type of Primary Energy	M.KW	Actual	%	Estimate	%
Hydro General	M.KW	17.80	5.7	19.50	3.7
Electric Pumped storage	M.KW	7.10		19.50	
Geothermal	M.KW	0.05	0.0	0.50	0.1
Domestic Oil Natural Gas	M.KL	3.50	0.9	8.00	1.3
Domestic Coal	M.TON	18.60	3.4	20.00	2.2
Nuclear	M.KW	6.62	1.7	26.00	6.1
Imported LNG	M.TON	5.06	1.8	24.00	5.5
Imported Coal (steam coal)	M.TON	62.34 (0.50)	13.1	93.00 (6.00)	12.0
Sub Total	M.KL	104.00	26.7	195.00	31.2
Imported Oil	M.KL	286.00	73.3	430.00	68.8
Grand Total	M.KL	390	100	625	100

causing reductions in the volume of proven deposits. When production reserve ratio (R/P) declines to a certain level (10-15), production increase reaches its limit. This is the physical limit of petroleum production increase.

On the other hand, it is doubtful if all oil countries will continue to produce petroleum at the maximum production rate. While countries whose economic developmental potentials are high (Iran, Iraq, Algeria, etc.) will need to increase their revenue by increasing oil production, oil countries of Arabian Penninsula will adopt policy to restrict the volume of oil production due to their excessive revenue from oil, as has already been done by Kuwait and the United Arab Emirates and will eventually be done by Saudi Arabia, the country of world's greatest petroleum resource. When Saudi Arabia curbs the production, oil production of the world will begin to shrink. It is highly possible that the transition from production increase to production decline will take place often the latter half of the 1980s.

If OECD countries fail to conserve on energy and to develop and to expand the utilization of a substitute energy by the time of this transition, but increase demand for OPEC oil, the world will suffer from an oil shortage. Industrial nations will fight each other for securing oil (in which USSR will join), and the price of oil will surely rise and the world politics and economy will be hurt substantially.

The lead time for energy conservation and the successful development of a substitute energy is from ten to fifteen years. Unless OECD countries establish a goal for reduced petroleum consumption in the future and immediately intensify their policy efforts for the energy conservation and substitution of petroleum chronic shortage of petroleum will be inevitable. And if this situation is not avoided, non-oil producing developing nations will be hurt seriously.

OUTLOOK ON COAL RESOURCES AND COAL MINING TECHNOLOGY. R. Yamamura.

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Since the end of the nineteenth century Japan has spent a great effort to the development of industries and made a splendid achievement in it. During this period, the coal mining industry had exploited coal mines in all parts of the country, and produced about 2.5 billion tons of coal for the use as the foundation of the development.

Japanese coal is geologically of Paleogene period of Cenozoic era. Being located at the edge of the Continent of Asia, it was subject to the influence of the orogenic movements which resulted in that, a wide range of coal varying from lignite to anthracete is available in Japan owing to the accelerated coalification, while the state of mines is worse than many other countries due to the geological deformation.

However, the difficulties in coal mining have been overcome to a consideralbe extent through the accomplishment of the advanced systems of the technologies for all mechanized long-wall mining, hydraulic mining, under-sea mining and centered control of mine safety, etc.

In order to meet the future global energy demand, the exploitation of the huge amount of coal resources in the countries around the Pacific is becoming important. Japan, as a member country with its energy being largely dependent on importation, is eager to cooperate with them by offering its mining technologies as well as its mine management knowledges.

GEOPOLITICAL ASPECTS OF NEW OIL: THE SEARCH FOR ADEQUATE AND CONTINUOUS SUPPLY

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However much energy forecasts vary, depending upon a large number of economical, geological, technical, and political assumptions, there is widespread agreement on certain trends. These are 1) if the industrial world experiences, over the next decade, a better-than-recent average economic growth rate of 4-4.5% and 2) if the energy consumption growth rate is nearly comparable, then the world community of nations will almost assuredly be competing intensely for oil in world trade. And if, as we have been warned will occur, the U.S.S.R. is included among these nations, there will then be an even greater increase in oil prices as a result of a chronic shortage of oil. For many importing states, the general condition will be one of an inability to compete with a few large energy consumers while coping with major social, economical, and political issues, and a lack of available alternative energy sources. Finally, underlying all these concerns will be the importance of Middle East supply as the major source of oil in world trade.

Dependence upon Middle East sources for a very high proportion of oil in world trade appears to be one of the "constants" in energy equations. Possessing today some 60% of proven and probable reserves, the Middle East may well remain the most prolific source of international oil through our lifetime. The Middle East today supplies the U.S. with nearly 50% of its oil imports (crude and products), approximately 80% of West Europe's import requirements, and 77% of Japan's. From nowhere else comes such a profusion of oil; there are no other truly giant conventional petroleum deposits (it is possible that Mexico's deposits could rival those of the Mid-East but the information is presently too incomplete).

Obviously, Middle East supply brings with it serious and mounting concerns. As long as it remains such an important source of world oil, we will have to accept that it is a commodity which is plagued by risks of continuing political instability whose origins are very deep in history; it is by no means summed up only in the Arab-Israeli dispute. We must understand that we are dealing with ancient rivalries derived from cultural, religious, and economic differences between the peoples of the Nile and the Fertile Crescent of the Tigris and Euphrates and between the Muslim peoples of the Arab world and those of Persia.

The contemporary usage of "Lebanon," "Syria," "Iraq," "Jordan," the "United Arab Republic" (Egypt), "Iran" (Persia), "Saudi Arabia," and "Israel," which implies nation-states of a form familiar to the Western world, misleads us again and again. Regardless of the modern names, we are still witnessing the break-up of one of the great imperial systems -- the Ottoman Empire. This fragmenting process is made infinitely more complex by the strategic importance of oil to the industrial world, and by the intervention of western powers into the affairs of the region.

The point should be clear that access to Middle East oil will always be inextricably bound to the prevailing political trends; it will not be expressed in relatively simple, commercial terms. The combination of these factors lends great urgency to the task of reducing dependence upon the region, by diversifying our sources of oil and encouraging the rapid development of non-conventional petroleum deposits (shale, tar sands, and the so-called "heavy" oils) and of alternatives to oil itself. Of all these courses of action, the search and exploitation of new deposits of crude are tasks which can be undertaken with minimum delay as the technology of exploration exists: we can lay the pipe, we have the tankers and the refineries already.

In order to minimize the "geopolitics" of oil, by decreasing one's dependence upon a single, politically sensitive area, one must take into consideration the number of factors which would contribute to easy access to oil. These would be seeking out regions for exploration which are 1) controlled by non-Communist countries; 2) distant from the Middle East; 3) dependent upon earnings from oil; 4) within a comparatively short distance from the commercial markets; 5) areas whose political objectives are such as to find them not part of any cohesive bloc; and finally, 6) regions whose reserves are of such magnitude that they would be useful alternatives to a reasonable proportion of Middle East supply.

In the case of Japan, for example, the most obvious "zones" of interest would center upon the prospective regions of offshore South East Asia, Indonesia, and the South China Sea. Others would be China (a future possibility), the Soviet East Siberian and Sakhalin fields (also a future possibility), Alaska, the Canadian Arctic, and Alberta (the last named Canadian sources being of considerable interest at the present time). Another Japanese security zone for alternatives to Middle East oil would also, surely, include some exports from Mexico and, eventually, from the Venezuelan Orinoco region.

By how much would Japan have to reduce its Middle East dependence to gain added security? Today, Japan imports a total of about 5 MMB/D; of that, 3.5 MMB/D come from the Gulf proper. The volumetric flow will increase, assuredly, with time. But if Japan had in existence a substantial strategic petroleum reserve (perhaps in the order of four months total imports, or 600 MM barrels) over and above an increased commercial inventory and were also fortunate enough to obtain perhaps 1.5-2 MMB/D from other zones, the problem of oil supply security for Japan might be manageable.

The United States is in a different situation. Faced with the prospect of declining onshore reserves and an uncertain amount of additional offshore oil, its present 50% dependence upon oil imports -- approximately 8 MMB/D (3 MMB/D than Japan's total imports) -- compels it to examine oil supply zones less vulnerable to disruption than the Middle East. An inner and primary zone would include Venezuela, Mexico, and Canada. Others, more greatly dispersed, would be Nigeria, the polar latitudes, and the Falkland-Argentine shelf.

The Orinoco Valley belt in Venezuela is still thought to contain one of the most extensive sources of oil with some 700 billion barrels of oil (perhaps 70 billion barrels recoverable by the application of known techniques). A conservative billion barrel estimate of Mexico's oil is 12 billion barrels "proven," 30 billion barrels "proven and probable," and 60 billion barrels "in place." The Canadian "heavy" oil and tar sands are, potentially, of comparable significance: possibly 954 billion barrels of oil, from which some 27 billion barrels could be put in the market using present day techniques.

The overlap of Japanese and U.S. oil security zones need be of no concern; the successful development of the great unexploited regions of Alberta, the Canadian Arctic, Mexico, and Venezuela would make available to the industrial world an additional volume of substantial size which would, in time, diminish the strategic significance of Middle East Oil.

These reserves are known to exist. We may not, at present, be fully cognizant of the necessary technology to exploit these diverse reserves, nor have the required funds, nor be sure of whether the various interested governments will use every incentive to encourage their exploitation. But the oil is there -- it does not have to be discovered.

Perhaps the greatest unknown is the political aspect, the extent to which government policy may encourage or inhibit exploitation. For example, current Canadian estimates warn, despite the enormous amounts of oil in the tar sands, and the existing heavy oil, that Canadian production is to decline (1978: 565 MMB/D; 1985: 282 MMB/D; and 1990: 221 MMB/D) while demand increases (1978: 687 MMB/D to 1990: 836 MMB/D). Is this to be the case?

Although none of these zones, from the Japanese, U.S., or the rest of the industrial world's perspective, is going to be developed soon, the launching of a major effort to exploit these resources would be an important signal to OPEC generally -- and to OAPEC in particular.

Thinking in these terms, one is reminded that the U.S. possesses a truly extraordinary oil resource whose extraction may prove to be not much more difficult than that of the deposits of Venezuela's Orinoco. The total oil in place in the U.S. oil shale deposits is estimated at 2 trillion barrels, of which 80 billion may be recoverable with current techniques. (Estimated production for 1980: 100 MB/D; for 1985: 400 MB/D, all based on present levels of commitment.) Apart from capital and technical problems, however, the successful exploitation of these shale deposits is made more difficult through other conflicting interests, such as environmental impacts on the surrounding regions, the diversion of scarce water supply, conflicts of jurisdiction and purpose between the Federal government and state governments and also between various agencies within the Federal government itself.

With all these complications, the present judgment is that, as vast as the shale deposits are, we are less likely to develop them as assiduously as we would the resources of other countries -- barring a shock similar to the 1973-74 Arab embargo. Yet it is this vast domestic resource (plus, of course enormous coal deposits) which makes the crucial difference between the U.S. and Japan.

Another factor which one must take into account in attempting to reduce dependence upon Middle East oil is the still largely unknown effects of enhanced recovery techniques -- prolonging the life of oil fields, thus permitting a greater volume of oil to be produced. It is the unique contribution of chemists, chemical and petroleum engineers, and geologists which has accomplished some of the task. There is hope that they may be able to make even greater strides in the area of enhanced recovery techniques. For example, the usual estimate for the extraction of oil without the employment of such recovery techniques is about 25%. As a general rule, the employment of secondary techniques (injection of water, gas) and the wider use of tertiary techniques (injection of heat and/or chemicals) may increase the amount of recoverable to 32%. It is possible that these techniques could increase the volume of oil from known reserves world-wide by as much as 250,000 MMB, thereby significantly prolonging their useful life.[1] There is every reason to believe that such techniques, applied under similar conditions, would also increase the overall yield of new oil reserves.

Confounding many of our hopes for limiting reliance upon the Middle East and increasing oil in world trade from other sources is the too-infrequently discussed subject of the "finding rate" for new oil. The brutal fact is that for the last thirty years -- outside the Middle East and the Soviet Union -- we do not believe there has been discovered a single proven or probable reserve of more than 25 billion barrels. Neither Libya, Nigeria, Alaska, the North Sea, nor Mexico qualify as exceeding that level. Yet, if we are to preserve a reserve-production ration of 10:1 (and some now advocate a more conservative ratio of 15:1) a discovery of such magnitude will be required annually -- the discovery of two North Slopes, if you prefer.

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[1] See Andrew R. Flower, "World Oil Production, Scientific American, March 1978, pp. 42 and 44.

Other views which divert us from a prudent thinking-through of oil supply problems are the classical economists' theory of supply always meeting demand, or that OPEC states will always be willing to produce enough oil for their "customers," or simply that oil has always been found when needed and will still continue to do so. The naivete of these views has yet to be appreciated.

The assumption that supply will meet demand for economic reasons ignores some of the realities of our crucial dependence on oil. It does not consider that in time of chronic shortage, a number of nations may both be unable to pay escalating costs for oil and, for reasons of their oil-dependent economies, be unable to go below a certain level of supply without risking an economic diaster, with severest social and political consequences. Wars have been fought over scarce resources. The "law" of the market place is not always one, when applied, that is accepted peacefully by all involved.

The argument found in so many forecasts of "OPEC Supply Required to Balance" should be banished from our midst unless qualified by the word "desired" for "required." We believe we have in Saudi Arabia an interesting and instructive example of why an oil exporter may find it to be in its own long term interest not to produce at levels desired or even required by oil consumers: it is wasting an irreplaceable asset; oil left in the ground is virtually certain to increase in value over time. If exported, the revenues from today's sales cannot be fully employed, so the surplus is invested in overseas markets whose ups and downs, combined with the erosion worked by inflation, warn of further losses.

There is a pernicious belief that the producing states are economic animals certain to pursue rational, economic goals (as defined by western, industrial states). Hence security and maximum supply can be taken for granted; if, in the passion of a moment, states should act irrationally, they soon come to their senses. It is a line of reasoning which should be re-examined.

Most curious of all is the near-religious conviction that undiscovered reserves of oil are vast and will be discovered in time to ease any future energy crunch. What is an "undiscovered" reserve? It is merely speculation based upon a mix of some geological evidence and surmise, for the most part, which may "prove" to be accurate. However, there is little scientific evidence to support these speculations and scarcely more practical application of drilling to further investigate such predictions.

The prudent man must inquire more into the likelihood that enough oil will be found to give us more time to accomplish a safe passage through what may someday be described as transition from our present dependence upon oil to the use of alternative energy sources.

The search for more adequate and continuous supply may well be unsuccessful; geology, economics, and politics may be against us. Time is not necessarily on our side and we cannot assume ultimate victory in terms of oil. Nor, however, can we just accept this pessimistic scenario; comprehending the scope of our problems may lead to a clearer concept of our opportunities. This is a point which does not appear to have been fully realized in the capital of the world's energy colossus -- the United States whose domestic energy options are so varied as to set it apart from most other industrial nations for whom foreign exploration may be the only alternative to continuing, large dependence upon imported oil.

AUSTRALIA'S ENERGY POLICY: A GAS UTILITY VIEW

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Australia has been called the world's largest island but it is really the world's smallest continent. Dry and sparsely inhabited, with only two cities of world renown and more sheep than people, the "Great South Land" (as early European explorers called it) is nevertheless a highly urbanised industrial country. Some 25% of civilian employment is in manufacturing, compared with 26% for Japan and 23% for the United States. Our gross domestic product in 1975 was 5,700 US dollars per head, compared with 7,120 for the United States and 4,450 for Japan. However, the Japanese economy was clocking up an average 7.8% real G.D.P. growth rate from 1960 to 1975, while Australia only managed 3.1% and the United States 2.5%.

Three million of Australia's 14 million population live in Sydney, the largest city. By contrast, about 9 million of Japan's more than 100 million people live in Tokyo and New York is home to about 8 million of the over 200 million United States citizens. The land areas of these three nations range from 377,000 square kilometres for Japan to 9,363,000 for the United States. Australia is a little smaller than the United States with 7,682,000 square kilometres. Her population, if evenly spread over the land mass, would live and work with a mere two persons per square kilometre. The comparable figure for the United States is 23 while Japan has 300 persons per square kilometre.

Only about 3% of Japan receives under 800 millimetres of rainfall annually, yet fully 88% of Australia is as dry as this. The United States figure is about 55%. Yet from Australia's dry northern and western regions comes exportable mineral wealth which now eclipses in value the agricultural staples on which the country has historically depended for external solvency.

A glance at the atlas will convey a better impression of Australia's economic assets and liabilities. First, as they say, the bad news. The continent is isolated from her four major trading partners, namely Japan (32% of exports/19% of imports), the United States (11% of exports/21% of imports), and the Association of South East Asian Nations (7% of exports/5% of imports). The distances in kilometres (by air) start at 3,347 (Darwin to Singapore), then climb through 7,817 (Sydney to Tokyo) and 11,242 (Melbourne to San Francisco), before reaching 14,500 (Perth to London).

Australia has not yet reached industrial maturity and is still a net importer of capital. The economic composition of imports reflects this fact, being heavily weighted in favour of plant and machinery, transport equipment, industrial inputs and fuels and lubricants. Finished consumer goods typically represent less than a fifth of total imports. The commodity composition of imports shows that mechanical machinery predominates with almost 17% of the total, followed by miscellaneous manufactures (13%), petroleum (10%), motor vehicles (10%), chemicals (9%) and electrical machinery (almost 9%).

The importance of transport equipment and fuels and lubricants in overcoming what one Australian historian has termed "the tyranny of distance" was foreshadowed in my remarks about isolation. The east-west distance from Sydney to Perth is 3,400 kilometres, with the Adelaide to Darwin journey from south to north almost as lengthy. To make matters worse, the bulk of Australia's secondary industry is situated within a narrow crescent connecting Sydney to Melbourne. The products issuing forth from Australia's south-eastern factories and workshops must be transported vast distances to reach consumers in the other capital cities and the country towns which serve the agricultural districts and mining projects to which I now turn.

Now for the good news. Australia's extreme geological age and size means that it encompasses most of the world's geological and climatic zones. Every mineral of commercial significance (except graphite and sulphur) is in production, along with such a quantity and variety of agricultural produce that food, beverages and tobacco represent less than 5% of imports. Australia's export income is principally generated by coal (12%); wheat, wool and iron ore (8% each); meat and alumina (6% each); and sugar (4%).

Australia's primary industries are much less geographically concentrated than its secondary ones. Coal from the productive seams around Blackwater fuels Queensland power stations and is exported through Gladstone. Wheat from the Wimmera-Mallee district around Horsham in Victoria is railed to flour mills in Melbourne and exported through Geelong. Wool from Goulburn in the Southern Tablelands of New South Wales is sold at auction in Sydney and exported. Iron ore from Mt. Tom Price in the Pilbara region of Western Australia is pelletized at Dampier and exported or shipped to the Kwinana steelworks. Bauxite is mined at Weipa in Queensland and treated to produce alumina, which is shipped to Bell Bay in Tasmania for smelting. Sugarcane is grown along the Queensland central coast and crushed in mills, with the product being exported through Mackay and other bulk handling ports. Uranium reserves are located in the Northern Territory in the far north, whilst oil and gas are produced in Bass Strait in the far south.

Within what kind of legislative restraints do Australian export industries operate? Politically, Australia is a federation of six States and two Territories. There is a bicameral Parliament in Canberra, the National Capital, consisting of a House of Representatives and a Senate on the United States model. However, the United Kingdom's Westminster system of government is followed, with an elected Prime Minister who appoints a Cabinet of elected politicians rather than calling on outside talent, as the American President does. The Senate is only nominally a House representing States' interests, as it almost always divides along party lines. Party discipline is strong within the current Government (Liberal Party/National Country Party) and Opposition (Australian Labor Party), so lobbying by interest groups is in general only successful if directed at the top men. Permanent heads of Government departments are also influential, as Acts of Parliament typically leave room for a lot of "administrative discretion", giving quasi-legislative power to the top bureaucrats. In addition, there are the Courts, who often place fresh interpretations on the Constitution, the Statutes and the Regulations made thereunder by the administrative wing of Government. The various State Parliaments operate in similar fashion, although of course confined to matters within their boundaries.

The Australian federation is more centralist than, say, the Canadian one, due to Canberra's control over the most lucrative tax bases, particularly personal incomes, sales turnover and imports. Power over the mining industry though, is much more under the control of the States. Each Government includes a Minister of Minerals and Energy (or equivalent), who approves applications for exploration leases. All minerals discovered become Crown property, but promising leases are almost invariably converted into mining tenements for exploitation by the successful prospecting company, which pays royalties to the Crown and may have to abide by other negotiated terms and conditions. The Australian Government receives a 40% share of offshore petroleum royalties and levies an excise tax on crude oil, although control of other seabed resources remains firmly in State hands.

Through its Bureau of Mineral Resources, the Australian Government supplies geological and economic information to the mining industry. It can control the export of certain metals, petroleum and petroleum products and all raw and semi-processed minerals. Government assistance is given in the form of income tax concessions on capital subscribed to mining ventures and direct subsidies to the industry. Commonwealth and State Ministers meet regularly to co-ordinate policies through the Australian Minerals and Energy Council.

Australia's Fossil Fuel Resources:

The problem of estimating Australia's energy resources is very difficult. An attempt has been made by the Federal Government's National Energy Advisory Committee (1) and most of the information in this note comes from this source. The term resources usually refers to that quantity of material that can be economically extracted. New technical developments and/or increases in prices can make previously identified sub-economic resources, economic. As well as identified resources there are usually considerable quantities of undiscovered resources (i.e. hypothetical and speculative). The National Energy Advisory Committee has used the McKelvey classification, Figure 1. On this basis, Australia's fossil fuel resources are shown in Table 1.

Table 1

Proven Economically Recoverable Australian Fossil Fuel Reserves - At December 1977.

(million terajoules)

State	Crude Oil	Natural Gas	Gas Liquids	Black Coal	Brown Coal	Total
Victoria	8.0	7.8	2.3	-	377*	395
New South Wales	-	-	-	252	-	252
Queensland	-	0.1	-	256	-	256
South Australia/ Northern Territory	0.3	3.5	0.9	9	4	18
Western Australia	0.8	18.8	3.4	8	-	31
Tasmania	-	-	-	2	-	2
Australia (approx.)	9.2	30.2	6.6	527**	381	954

* Based on 38 580 megatonnes of economically recoverable resources.

** Based on 20 260 megatonnes of economically recoverable resources.

Sources:

Crude Oil, Natural Gas and Gas Liquids - The Petroleum Newsletter No. 72 - Department of National Development.

Black Coal and Brown Coal - Australia's Energy Resources - an assessment. National Energy Advisory Committee No. 2.

Note 1 : Total figures are rounded out to the nearest whole numbers.

Note 2 : Resources which are relatively very small have been omitted.

Note 3 : Gas liquids are shown separately from crude oil and natural gas. Commonly, they occur together in the ground, but are separated in the treatment plant immediately after extraction, and are therefore quoted separately.

Note 4 : Western Australian Petroleum reserves includes those at Carnarvon and Bonaparte Gulf.

Note 5 : Conversion factors (average) - terajoules x 10^6 = 237 million barrels of gas liquids.
= 166.3 million barrels of crude oil
= 0.92 tcf. of natural gas
= 38.4 million tonnes of black coal
= 102.5 million tonnes of brown coal

Although the above Table 1 follows the McKelvey classification, the figures for crude oil, natural gas and gas liquids include the reserves of the North West Shelf. The North West Shelf fields although not currently being produced have been included as they are presently being assessed for future development. Table 1 lists only conventional fossil fuels and ignores shale oil, uranium and thorium.

The following comments expand the information shown in Table 1 for the various fuels.

Petroleum Fuels:

(a) Crude Oil:

At December, 1977 some 9.2 million terajoules (TJ) of crude oil was estimated to be economically recoverable. This is a known and demonstrated quantity. Potential still exists for more discoveries (1). It is estimated that a 90% probability exists for finding an additional 9.3 million TJ (1,550 x 10^6 barrels). To find an additional 39.1 million TJ (6,500 x 10^6 barrels) the probability is believed to be around 10%.

(b) Natural Gas:

The economically recoverable quantity of sales gas is put at 30.2 million TJ (28 tcf.). As with crude oil, potential still exists for future discoveries. The probability of finding an additional 32.9 million TJ (30 tcf.) is estimated at 80%. This probability declines to only 20% for an additional 65.8 million TJ (60 tcf.).

(c) Gas Liquids:

This includes condensate and L.P. gas. In terms of size they are an important resource and total 6.6 million TJ (1,560 x 10^6 barrels). This is not much smaller than crude oil at 9.2 million TJ. It is considered (1) that an 80% probability exists for finding an additional 5.2 million TJ (1,240 x 10^6 barrels). To find 16.8 million TJ (3,980 x 10^6 barrels) the probability is only 20%.

Black Coal:

The economically recoverable quantity of black coal shown is 527 x 10^6 TJ (20,260 million tonnes). However, there are at least 4.4 times this quantity in the identified inferred category as shown on Figure 2.

Identified sub-economic resources of coal are very large. For example, the Cooper and Pedirka Basins in South Australia contain 3 trillion tonnes of coal (78,000 x 10^6 TJ) at a depth between 1,400 and 4,000 metres. In addition, considerable scope exists for future discoveries. Figure 2 summarizes the position for black coal. It is important to note that as the price of black coal increases or as new technologies develop the quantity of coal classified as an economic resource can be increased considerably.

Brown Coal:

Economically recoverable brown coal is situated primarily in Victoria and totals 381 x 10^6 TJ (39,000 million tonnes). Identified and demonstrated sub-economic resources total an additional 265 x 10^6 TJ (27,128 million tonnes). Identified and inferred sub-economic quantities are very large with at least 54,000 million tonnes in Victoria. Undiscovered categories are also likely to be large. Figure 3 summarizes the position for brown coal.

Australia's Fossil Fuel Demand:

A demand forecast for internal consumption to the year 2000 has been prepared using the Federal Government's Department of National Development latest projections (2) to 1986/87 and then extending those to the year 2000. Average growth rates, annusl use and cumulative demand to the year 2000 are shown in Table 2.

Table 2

Fuel	1976/2000 Growth p.a.	Annual Use TJ x 10^3 1976	2000	Cumulative Demand TJ x 10^3 1976/2000
Black Coal	4.8	749.9	2 289.7	35 315.5
Brown Coal	4.0	289.9	753.4	11 980.9
Oil	2.6	1 255.3	2 331.6	44 250.5
Natural Gas	5.7	212.8	800.9	14 152.8
Total	3.8	2 507.9	6 175.6	105 699.7

Table 3 shows the relationship between the cumulative use of fuels from 1976 to the year 2000 and total economic resources of fuels.

Table 3

Fuel	Cumulative Demand TJ x 10^3	Economically Recoverable Resource TJ x 10^3	% Depleted
Black Coal	35 315.5	527 000	6.7
Brown Coal	11 980.9	381 000	3.1
Oil	44 250.5	9 200	- 381.0
Natural Gas	14 152.8	30 200	46.9

The position for oil and natural gas is not good. The cumulative requirement for natural gas will result in the consumption of almost half the economic resource by the year 2000. This however, understates the position as 18 x 10^6 TJ of natural gas are located at the North West Shelf and will be used primarily for export. For oil the situation is even worse as known reserves are completely inadequate representing only 21% of the cumulative demand to the year 2000.

Australia is well endowed with black and brown coal. Cumulative consumption of black coal to the year 2000 of 35 million TJ will only consume 6.7% of current economic resources. With 60 x 10^6 tonnes of black coal exported per annum for 24 years at an average heating value of 26 gigajoules (GJ) per tonne an additional 37 million TJ would be consumed. With exports and domestic consumption 13.8% of the black coal resources would be utilized. However, as noted in the previous section it is estimated that there is at least 4.4 times the quantity of black coal stated in Table 3 that is suitable for mining. With these resources the percentage used by the year 2000 would be close to 3%.

The position for brown coal is good with only 3% of economically recoverable resources being used by the year 2000. Considerable potential exists for enlargement of these resources.

Natural Gas for the Future:

As explained earlier, the population of Australia and the major concentration of its industry is in the south-eastern corner of the continent. The resources of natural gas not yet committed to customers and the most prospective areas for further gas discovery are in the north-western corner. The distance between these two is 4,000 kilometres and the cost of a pipeline system to bring this gas to Eastern States was estimated (3) in 1976 to be $1,600 million. The alternative of liquefaction in the north-west and transport by ship to the Eastern States, evaluated over a 20 year period, was less attractive than a pipeline.

Such a pipeline must cross four State boundaries, and its cost would be such that the gas utilities could find difficulty in financing such a project. It would therefore seem appropriate for it to be a Commonwealth Government project but so far the Government has not made any commitment.

Against the background of resource availability described earlier all gas utilities are confronted with planning problems. The following description of those confronting the Gas and Fuel Corporation of Victoria is given as a typical example.

The Gas and Fuel Corporation supplies 700,000 residential consumers and in addition, supplies industry in the reticulated area with 81% of its secondary energy needs (excluding electricity). It has maintained a strong campaign to convert all stationary uses of liquid fuels to natural gas both in its own interest and in its perception of the interest of the Government to minimize dependence on oil. The natural gas distributed in Victoria is obtained from the Bass Strait gas and oil fields under long term contracts which also provide options over any future discoveries. It is assumed in forecasts of the future that the price of gas from these sources will allow natural gas in the market place to maintain its competitiveness with oil and electricity. Competition does exist from solid fuels but is limited to very large users away from urban areas where clean air requirements make solid fuel uncompetitive. Market growth for natural gas will therefore be dependent on such fundamentals as population growth, industrial development and changes in living habits. On the other hand, growth may be neutralized by community adoption of energy conservation objectives, such as insulation of homes, re-cycling of materials, efficient designs of homes and efficient designs of industrial equipment. There are great unknowns in this area but the best estimates to date indicate that known reserves of natural gas in Bass Strait are equal to the cumulative demand up to 2005 at least, and success in conservation education could extend this period.

This does not however take account of the deliverability of gas from the reserves. When a comparison is made of the best estimate of maximum deliverability from the Bass Strait fields with the maximum daily demand of the market, it is found that a shortfall could exist from 1990 onwards. There are many solutions to this problem, partly from the demand and partly from the supply side. From the demand side conservation should be looked at seriously.

The Corporation is engaged in a major programme of community education. It is actively engaged in the promotion of insulation, it runs energy management courses for industry and provides technical consultancy services to industry. It has sponsored and built demonstration low energy homes. It operates a central energy information centre to provide information to the public. It is developing and demonstrating gas/solar installations for domestic and commercial use. This programme is aimed at reducing the use of gas by wise use, not by conversion to some other form of energy which could be against the national interest. Success in the programme could postpone the deliverability shortfall into the late 1990's.

From the supply side we can consider a number of solutions:

Storage:

The prospects of increased peak deliverability through the use of storage in geological structures are doubtful. At present an L.N.G. peak shaving plant is being built and expansion of this concept is a likely means of postponing peak deliverability problems. In addition, of course, such storage gives security against plant and platform breakdowns and thus serves a double purpose. The present plant is being built in conjunction with an air separation plant producing oxygen and nitrogen and it is hoped that the combined plant will give significant energy savings as well as capital cost savings.

Discovery of Additional Reserves in Victoria:

Exploration in Victoria to date has been concentrated in the Gippsland Basin offshore. What exploration has been carried out onshore and in the offshore Otway Basin has had no success, and active exploration in these areas has ceased. Even in offshore Gippsland there have been no additions to gas reserves by new discoveries for many years. Nonetheless, it is believed that diligent exploration could yield new gas discoveries sufficient to provide the required deliverability through the 1990's. To this end, the Corporation has set up an exploration subsidiary which in conjunction with a joint venturer has commenced exploration over 2,500 sq. kilometres offshore Gippsland.

New Long Term Supply Sources:

Chief amongst these lie the prospective resources of the North West Shelf. However, the problem of transport across the 4,000 kilometres to a market which will be small at the start and grow as a result of market growth and reduced deliverability from existing sources, is difficult to solve without some form of Government involvement in the financing of the lines and explicit Government policy on availability of reserves of gas.

Another alternative long term supply source is S.N.G. from brown coal of which there are tremendous reserves in Victoria. Since it does appear that S.N.G. from brown coal can be delivered to the market at a price competitive with oil from brown coal or electricity from brown coal, this should be a viable alternative by the late 1990's and may well be, in the long term, the main source of gaseous fuel to the State.

As can be seen, the solution to the supply problem in Victoria does not present any technical difficulty. All the above alternatives are possible with today's technology. The difficulty lies in the choice of the most effective method or combination of methods. For example, the lead time for an S.N.G. from a coal plant might be ten years and for a trans-continental pipeline 7 years. A lot could change during this time so that a decision to take one route as against another could be found to be incorrect with disastrous financial consequences.

The first priority therefore must be to remove the risk of such error being caused. The major change that can take place during a 6-10 year gestation period to secure long term supply is new discoveries of gas close to Victoria. For this reason exploration throughout Victoria and adjacent areas must be carried out as soon as possible. This does not necessarily suit the private enterprise explorer looking for immediate inland sales. Consequently some Government or utility intervention either to carry out exploration or to compensate the explorer for his holding costs seems to be necessary. Assuming that this exploration work has still shown a demand for North West Shelf gas in the Eastern States, a prior requirement for construction of a pipeline is the dedication of reserves to it to ensure its economic viability. At present the Commonwealth attitude to export of L.N.G. is uncertain. Permission has been given to export 52% of the present known commercial reserves which after allowance for plant fuel and losses is equivalent to almost 65%. For such a project as this pipeline at least 20 year's requirements would seem the minimum dedication. This quantity does not seem available at present.

Taking our risk minimizing exercise a step further, even with North West Shelf gas, a case can be made for the installation of a coal conversion plant in 1990's. However, the capital cost of these plants and the risks inherent in such a large project makes it unlikely that any utility could afford a plant of the required size without Government involvement in the financing and risk sharing.

All in all this points towards an inevitable Government involvement in ensuring the continued smooth supplies to customers in Eastern Australia.

Summary:

From this description of the particular problems of one gas utility, general conclusions with regard to a national energy policy can be drawn. If it is desirable to minimize Australia's dependence on oil, then widespread replacement of oil in stationary applications by gas should be encouraged. To achieve this, confidence in long term availability and stability of price must be encouraged by:-

(a) Government action to ensure a proper level of exploration by all possible means.
(b) Explicit Government policy on natural gas export so as to maintain sufficient resources dedicated to inland use to justify investment in distribution and utilization facilities.
(c) Government commitment either to construct or to guarantee the viability for private investors of large energy projects such as a trans-continental pipeline and coal conversion plants.

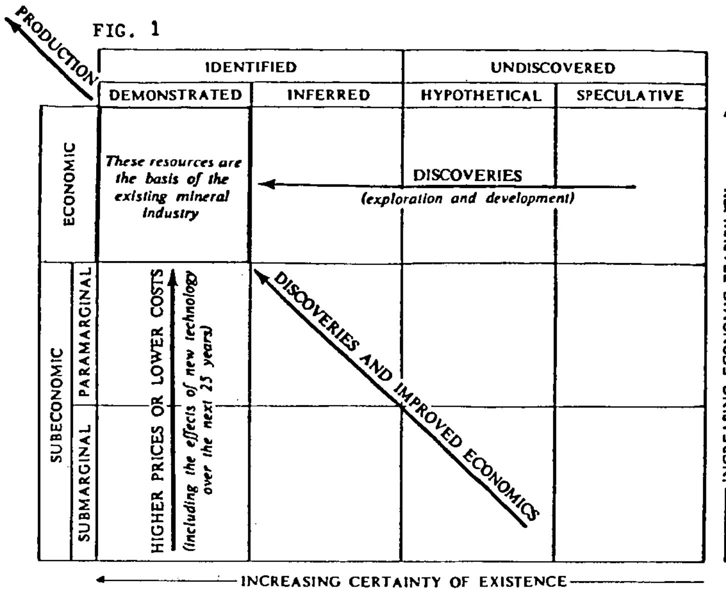
References:

1. Australia's Energy Resources, an assessment. National Energy Advisory Committee Report No. 2.

2. Demand for Primary Fuels Australia 1976/77 to 1986/87. Report by Department of National Development - April 1978.

3. Australian Natural Gas Utilization and Transportation Study. Prepared for The Pipeline Authority - October 1976.

FIG. 1



Resource classification diagram showing the general progression of non-renewable resources as a result of exploration, research, development and production.

FIG. 2 AUSTRALIA'S RESOURCES OF BLACK COAL (10⁶ tonnes)

		IDENTIFIED		UNDISCOVERED	
		DEMONSTRATED	INFERRED	HYPOTHETICAL	SPECULATIVE
ECONOMIC		In situ 36 300 (a) Recoverable Coking 11 880 (a, c) Non-coking 8380 (a, c)	In situ At least 160 000 Recoverable At least 89 000 (b)		
SUBECONOMIC	PARAMARGINAL	Very large (d)		Very large (d)	Relatively small (d)
	SUBMARGINAL				

← INCREASING CERTAINTY OF EXISTENCE —— INCREASING ECONOMIC FEASIBILITY →

(a) Results of drilling since 1973 will increase this figure. (b) A mining recovery rate of 55.8 per cent is assumed (see text). (c) For reasons given in the text, distinctions between coking and non-coking coals are becoming increasingly less meaningful. (d) No quantitative assessment available.

FIG. 3 AUSTRALIA'S RESOURCES OF BROWN COAL (10^6 tonnes)

		IDENTIFIED		UNDISCOVERED	
		DEMONSTRATED	INFERRED	HYPOTHETICAL	SPECULATIVE
ECONOMIC		In situ 40 930 (a) Recoverable 39 000	Small (b)	Very large (b)	Small (b)
SUBECONOMIC	PARAMARGINAL	In situ 27 128	Very large (c) (Only partly assessed)		
	SUBMARGINAL				

INCREASING ECONOMIC FEASIBILITY →

← INCREASING CERTAINTY OF EXISTENCE

(a) Total includes 5000 million tonnes in Victoria located beneath township planning scheme areas.

(c) Includes at least 54 500 million tonnes in Victoria. (b) No quantitative assessment available.