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RESOURCES AND ENERGY - A GLOBAL STUDY OF THE FACTORS INFLUENCING THEIR ACQUISITION

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INTRODUCTION

The issue of available energy is central to any resource assessment. Certain minerals are essential catalysts for established industrial processes, but in general the processes can either be replaced by alternative processes or be sustained by recycled materials, providing there is available energy. Energy itself cannot be recycled.

It could be concluded that petroleum is the energy source available to man possessing the highest thermodynamic potential, i.e. available energy. (It seems unlikely that the popularity of petroleum is a cultural obsession rather than the exploitation of the most easily won and most easily used energy resource). One could argue that the economic and industrial expansion of recent history could not have been fired by a different energy base, e.g. coal. The thermodynamic potential of coal and all other possible energy sources, i.e. shale oil, tar-sand oil, gas, nuclear fission, nuclear fusion, hydro, solar, wind, tidal and geothermal may be significantly smaller than oil. (Thermodynamic potential encompasses energetic costs of extraction, transportation, deployment, storage, etc.). Further more there must be some doubt that nuclear, tidal, wind, hydro, solar and geothermal technologies, deployed on a significant scale, can exist in the absence of large fossil fuel subsidies.

It follows also that any energy system based on any one or a mix of the alternative technologies may not support the economic and industrial superstructure inspired and sustained by oil.

Qualitative considerations alone, e.g. oil politics, nuclear power programme delays and uncertainties, point to a course of extreme prudence in the use of all fossil fuel resources. At current and anticipated rates of extraction their lifetimes are very brief indeed. Many years may pass before knowledge has developed to that point when it is known with acceptable confidence that sustainable alternative energy technologies can exist in the absence of petroleum or other fossil fuel subsidies. Until this wisdom has been assimilated, a strategy of energy thrift would be sensible. This ethic may automatically encourage conservation of other resources and capital.

Section 1. Resources - Current Estimates of Deposits

At the present time there exists what are probably adequate data on the extent of all important natural resources. Current consumption rates and growth rates of important non-renewable resources are also known to a reasonable degree of accuracy. Thus taking a piecemeal view, the life of each of these non-renewable resources can be estimated assuming that past trends continue into the future.

Such time-series extrapolations assume that factors such as relative monetary cost, relative labour cost and relative energy cost per unit resource extracted and produced will not affect established consumption patterns. They also ignore political action. Many of the resources are essential 'catalysts' or 'vitamins' in the extraction, refining and manufacture of other resources, i.e. there is considerable inter-dependence between combinations of these resources in specific situations.

A concise assessment of the resource position, without the intelligence gleaned from an inspired modelling exercise, can therefore be little more than superficial.

Data

1.1 Non-renewable sources

1.1.1 Petroleum resources

U.S.A.	100×10^9 barrels
Western Europe	30×10^9 barrels
North Sea	20×10^9 barrels
South America	130×10^9 barrels
Middle East	740×10^9 barrels
Other Regions	90×10^9 barrels
U.S.S.R. and China	490×10^9 barrels
WORLD	1800×10^9 barrels

These resources consist of 30 per cent discovered, 60 per cent presumed - on a world scale. A recovery efficiency of 40 per cent is implied.

1.1.2 Petroleum Consumption

U.S.A.	5.4 x 10^9/year	5% growth rate
Western Europe	4.7 x 10^9/year	10% growth rate
United Kingdom	0.8 x 10^9/year	
Japan	1.7 x 10^9/year	17% growth rate
World	20 x 10^9/year	3.9% growth rate

1.2 Natural Gas and Natural Gas Liquid

		Nat. Gas Liquids	Nat. Gas
Estimated	WORLD	330 x 10^9 barrels	1.8 x 10^{12} equiv. barrels
	North Sea	4 x 10^9 barrels	22 x 10^9 equiv. barrels

Most recent estimates for Brent Field (N.S.) are 1000 cu ft/barrel extracted. These are very rough estimates based on proven and estimated oil reserves.

i.e. 6000 cu ft/bbl Nat. gas .2 bbls/bbl Nat. gas liquids

1 cu ft $\doteq$ .18 x 10^{-3} bbls. Ref. Resources and Man

1.3 Tar or Heavy Oil Sands/Shale

Resources depend on development of viable technologies.

WORLD SHALE (recoverable)	180 x 10^9 barrels	(99.2% of shale not considered recoverable with anticipated technologies)
EUROPEAN SHALE	30 x 10^9 barrels	
Tar-Sands (Canada)	300 x 10^9 barrels	

1.4 Coal

U.S.S.R.	4.3 x 10^{12} tons	
U.S.A.	1.48 x 10^{12} tons	
Asia	.72 x 10^{12} tons	
Canada	.59 x 10^{12} tons	
Europe	.38 x 10^{12} tons	West Germany 62% U.K. 36%
Africa	.09 x 10^{12} tons	
South America	.023 x 10^{12} tons	

NOTE: NCB put British reserves as 100 years at current extraction rate, i.e. 140 x 10^6 tons p.a.

1.5 Uranium

At the present time only reserves producing ore (U_3O_8) at up to $10/lb are worked

	Reasonably Assured	Estimated Additional
WORLD (Non-communist)	835,000	740,000
U.S.A.	310,000	350,000

Approximate Distribution of Non-Communist Reserves

U.S.A	47%
Canada	22%
South Africa	9%
France, Niger, Gabon, Cont. Af. Rds.	7%
Argentina, Brazil, Australia, Italy, Japan, Mexico, Portugal, Spain	12%

Speculative estimates for U_3O_8 at up to $30/lb are:

Reasonably Assumed	Additional
2.1×10^6 tons	3.5×10^6

Source: 1967 report by European Nuclear Energy Agency and International Atomic Energy Agency

1.6 Other Non-renewable Natural Resources

Resource	Estimated Reserves	Current production	Static Index	Average projected growth	Exp. Ind.
Aluminium	1070×10^6 tonnes	11×10^6	97 years	6.4%	31 years
Chromium	703×10^6 tonnes	1.7×10^6	410 years	2.6%	95 years
Cobalt	22×10^5 tonnes	$.2 \times 10^5$	100 years	1.5%	60 years
Copper	280×10^6 tonnes	7.8×10^6	36 years	4.6%	21 years
Gold	14×10^3 tonnes	1.3×10^3	11 years	4.1%	9 years
Iron	880×10^8 tonnes	3.7×10^8	240 years	1.8%	93 years
Lead	93×10^6 tonnes	3.6×10^6	26 years	2.0%	21 years
Manganese	73×10^7 tonnes	$.75 \times 10^7$	97 years	2.9%	46 years
Mercury	183×10^3 tonnes	10×10^3	18 years	2.6%	13 years
Molybdenum	49×10^5 tonnes	$.62 \times 10^5$	80 years	4.5%	34 years
Nickel	680×10^5 tonnes	6.1×10^5	110 years	3.4%	53 years
Platinum	14×10^3 tonnes	$.12 \times 10^3$	120 years	3.8%	47 years
Silver	177×10^3 tonnes	10×10^3	18 years	2.7%	13 years
Tin	420×10^4 tonnes	23×10^4	19 years	1.1%	15 years
Tungsten	130×10^4 tonnes	3.3×10^4	39 years	2.5%	28 years
Zinc	106×10^6 tonnes	5.1×10^6	21 years	2.9%	18 years

Sources: Sir Kingsley Dunham, 1972 and Limits to Growth

Section 2. Discussion

Non-renewable resources

1.1 Fossil Fuels

1.1.1 Petroleum

Very significant inroads have been made into the world's petroleum capital.

If current growth in consumption patterns continue unchecked then the forces concomitant with a natural resource cycle may force a decline in the late 70s or early 80s on a global scale. It is possible there could be localised declines prior to the global decline, (H. R. Warman, B.P. 1973, King Hubbert in "Resources and Man").

Political manouvering may distort the normal resource exploitation cycle and precipitate an earlier decline.

On the European stage, indigenous petroleum resources would, if it were possible to extract at such a rate, satisfy between five and ten years demand at its present level, i.e. approximately 5×10^9 barrels per year. The bulk of European oil is located in the North Sea. Developing these reserves is a very expensive project, i.e. over 40 x the development cost of similar fields on land. Thus capital is consumed which would otherwise have been used in other endeavours.

The best extraction techniques employed still leave 60 per cent of the original petroleum in the ground. Improving the extraction efficiency would demand considerable pumping energy. There may not be a net energy gain or the industrial system may not leave sufficient energy. The oil currently being consumed has been won with a relatively small investment of capital equipment, prospecting, energy and human labour. The existence of this easily won, easily transported and easily refined fuel may be the primary impetus for the economic growth experienced in recent history. Countries with high growth performance have a preponderance of petroleum in their economies, from 70 per cent, U.S.A. to 98 per cent, Japan. If growth and easily won petroleum are significantly correlated, then the future will surely see at least a reduction in growth due to the fact that in one way or another more of a nation's working hours, capital and energy is directed at securing the resource.

1.1.2 Natural Gas

The magnitude of world natural gas reserves is not known with anything approaching the precision of petroleum reserves.

Some estimates suggest that the original energy value of natural gas matched that of the original petroleum reserve. Unfortunately, much of the gas being discharged at remote wells is burned at the well head. Obviously gas is not as versatile a fuel as oil and its exploitation demands a significant capital investment in the form of pipelines, specialised tankers and more specialised storage procedures, especially for mobile installations.

The energy content of North Sea gas may effectively double the energy value of the oil reserves. This will at least offer a longer breathing space.

1.1.3 Tar or Heavy Oil Sands/Shale

The shale-oil production in southern Scotland ceased some years ago because of poor operating economics.

Compared with petroleum extraction, it is a very capital, energy and labour intensive business. There are no shale deposits currently being worked in the U.S.A., which appear to be the only significant deposits. There are at least two major problems in winning shale oil, first, the pollution problem accompanying a massive-strip mining operation and second, the technological problem of engineering a plant which can process approximately one ton of shale a second.

The only tar sand deposits mentioned are those in Alberta, Canada. Athabasca being much the largest. There is one 45,000 barrel a day plant currently operating. Approval is pending for a 150,000 barrel per day plant. Availability of water and pollution could limit large scale operations, as for shale oil working. Tar sand demands a very large investment in money, men and machines, the 150,000 b.p.d. plant will have a work force of 1,500 compared with a conventional oil well producing the same output with seven men.

The maximum rate at which these resources can be developed and their ultimate extraction rate will be some function of the complexity and difficulty of the extraction process. Compare cycles from oil and coal, Fig. 1 and Fig. 2.

1.1.4 Coal

Coal reserves represent over 90 per cent of the ultimate recoverable fossil fuel energy.

If coal is constrained by a cycle similar to other natural resources then the economic phenomena which is conventionally assumed to be "economic growth" cannot be sustained at recent rates of expansion by coal. King Hubbert's cycle for world coal extraction features a maximum growth rate of 3.6 per cent, and obviously this cannot be sustained indefinitely. The growth rate of petroleum extraction in recent times has been around 7 per cent. There is implied here the notion that economic growth and energy consumption growth are not only highly correlated but that the economic growth function is dominated by the energy consumption variable.

1.1.5 Discussion on Fossil Fuels

Fossil fuels cannot be provided in sufficient quantities for feeding the "sustained growth" ambitions of the world. Some developments in the use of fossil fuels, coal in particular, will severely reduce the net energy available to society.

The practices of coal liquefaction and gasification are energetically extremely wasteful. The energetic conversion efficiencies are very approximately 60 per cent.

Fossil fuels could provide very useful energy sources for many hundreds of years with restrained use. Reducing petroleum consumption to one tenth of the present rate would extend its lifetime to 1000 years. A parallel conservation measure for coal would stretch the life-cycle to 10,000 years. Should we plan for the legacies left to our descendants in 10,000 years?

1.2 Nuclear Power

1.2.1 Fission

At present nuclear reactors burn U-235 at the rate 1.2 k gm/MW/year.

Projected growth figures for nuclear power plants in the non-communist countries are given below. The cumulative consumption figures for uranium assume the whole of the additional capacity comes on line in the year indicated.

	Capacity	Annual consumption	Cumulative
1971	23,400 MW	4,000 tons	4,000 tons
1975	96,000 MW	16,000 tons	32,000 tons
1980	277,000 MW	47,400 tons	113,000 tons
1985	570,000 MW	95,500 tons	287,000 tons

These projections are supported by a recent OECD report, which anticipates an annual demand in 1985 of 100,000 tons.

By 1985, the present reactor programme would have consumed 40 per cent of the non-communist world's reasonably assured uranium resources. Another five years operation without further expansion in installed plant would see reasonably assured resources exhausted. The response of OECD to this fact of life is "It is therefore essential that urgent steps be taken to increase the rate of explorations for uranium so that adequate reserves may be maintained".

Clearly conventional nuclear fission reactors will have a very short history and their contribution to supplies, although probably significant, can never be dominant, i.e. possibly 20 per cent of current energy consumption in 1985.

Arguments which speculate that escalating energy costs and scarcity will make poorer ores economic may be delusive. One can foresee a situation with very tight energy supplies and free market forces could make energy extremely expensive and, therefore, energy intensive mining operations prohibitively expensive. Furthermore this argument is anticipating an increasing energy investment in mining operations in a situation of contracting energy supplies. Energy to do the job may not be available no matter how much one is prepared to pay.

1.2.2 Breeder

Fissionable nuclear fuel supplies may be expanded through the use of breeder reactors. Considerable effort has been directed at developing breeder reactors but at the present time there is little evidence of the existence of a viable commercial design. Breeders are a more exacting design and engineering problem compared with normal burners. It is an engineering fact of life that only very well established processes can be designed with confidence from the "text book". Unique engineering solutions must prove themselves in operation so that every hidden idiosyncratic reliability and safety problem will be given opportunity to emerge. It would be foolish to bank on a viable breeder technology emerging. After 25 years experience with non-breeders there must be some doubt that adequate designs have been evolved.

A viable breeder-reactor system will need to be developed and deployed to a very tight time schedule. Otherwise the continuing operation of non-breeder reactors may deplete reasonably assured uranium reserves.

The expansion rate for breeder reactor systems employing uranium is constrained by the breeding rate. The fuel doubling time is estimated to be ten years. Thus commencing with a starting stock of uranium the maximum expansion rate would be 7 per cent per annum, assuming that capital is available for this rate of expansion. The capital investment is likely to be massive by current standards and it remains to be seen how much of a contracting energy budget could be apportioned for this investment. The capital problem will be aggravated if at the same time it is necessary for the industrial system to create a mining and refining industry capable of winning very low grade uranium ores, e.g. granite.

1.2.3 Fusion

The tritium-deuterium fusion reaction holds the most promise of producing a self-sustaining fusion reaction.

Lithium 6 is the principal source of this mineral. The United States of America appears to possess the bulk of extractable ore. There are other smaller ore bodies in Canada and Rhodesia. It has been suggested by R. S. Pease that lithium 6 is recoverable from the tippings of Cornish china clay workings. Recovery from the sea is also a possibility.

The lithium-deuterium reaction would be sustained by two reactions.

$$D + T \rightarrow He + n + Energy$$
$$Li + n \rightarrow He + T + Energy$$

The primary reaction demands an ignition temperature of about 100 million ^{o}C. The plasma being contained within a toroidal vacuum reactor vessel by strong magnetic fields.

Such a design contains some fundamental engineering dilemmas. The breeding blanket would contain liquid lithium at about 1000^{o}C while the powerful super-conducint helium-cooled magnets, only 6½ feet away, must be maintained at -270^{o}C.

Because of the complexity of the experiments and the financial investments required, European countries are already having to co-operate in fusion research. The pursuit of controlled fusion is, without doubt, the most difficult task that man has ever attempted. Even though some of the most brilliant minds in the world are engaged in this research it is impossible to forecast whether fusion will ever be successfully achieved. Success would appear to be at least decades away.

1.3 Conclusions on Energy

1. All fossil fuel reserves will become depleted very soon at present consumption rates.

2. Petroleum reserves will become depleted first, at present extraction rates, and will force on society a much more restrained life style.

3. Nuclear power will experience a very brief history if technical capital and environmental causes conspire to prevent the establishment of viable breeder and fusion reactor systems. The life of non-breeder fission reactors may be contracted by global shortages of fossil fuels prohibiting energy intensive mining and refining.

4. Should society gamble on the success of either breeder or fusion energy developments and ignore the massive capital requirements necessary for their deployment, it may in so doing pre-empt the development of other sustainable (with small fossil-fuel subsidy) energy systems. These systems would probably be of medium to low intensity, such as solar, wind, tidal, hydro and geothermal.

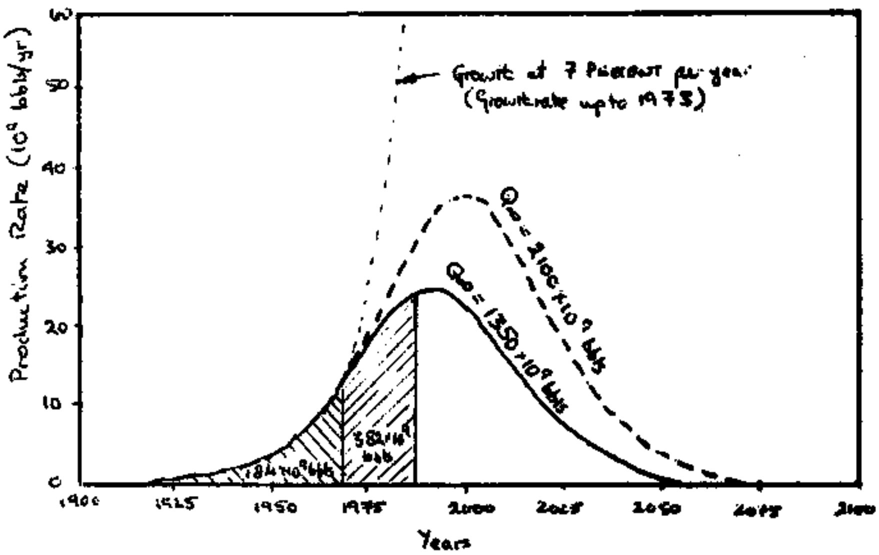

FIG. 1.

Complete cycles of world crude-oil production for two values of Q_{oo}

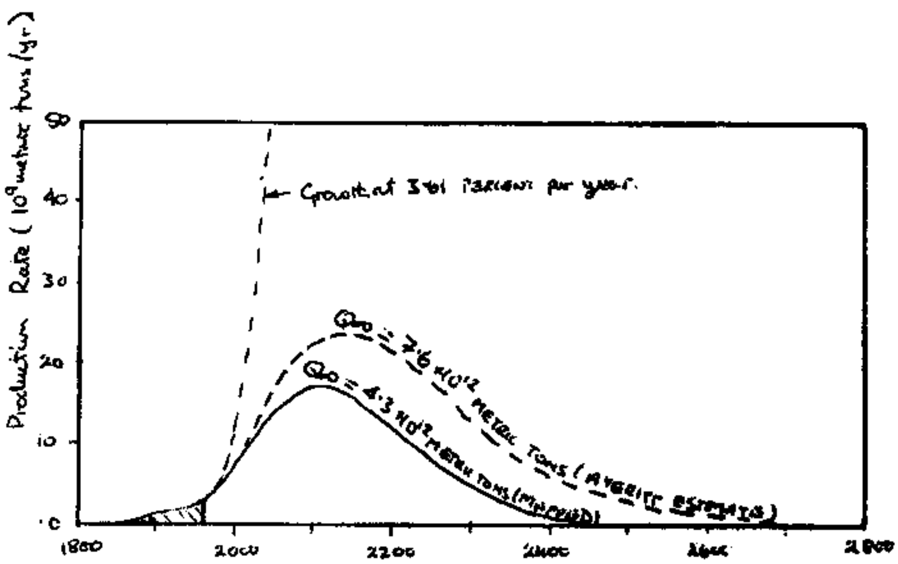

FIG. 2.

Complete cycles of world coal production for two values of Q_{oo}