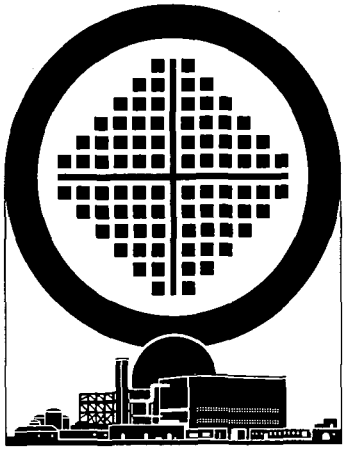

The World Energy Context

by Rurik Krymm

Over the last two decades (1950 - 1970), total world energy consumption rose at a rate of 5.2% overall and 3.3% per capita, almost trebling from 2.6 billion tons of coal equivalent (T.C.E.) in 1950 to about 7.2 billion T.C.E. by 1970. Over the next thirty years to the turn of the century, the slowing down of the rates of growth of energy consumption in industrial countries is expected to be substantially offset by the acceleration likely to take place in developing nations, so that the overall per capita world rates are likely to decrease only marginally. **Table 1**, which is based on correlation of energy consumption with relatively modest per capita increases in gross domestic product indicates the possibility of a quadrupling of energy demand by the year 2000 when it would reach a level of 29 billion T.C.E.

The rapid increase in total energy consumption during the last twenty years has been accompanied by radical structural changes in the shares of the different fuels, as illustrated in **Table 3.** The ratio of solid to gas and liquid fuels, which was close to 2/3 in 1950 was reversed by 1970, so that petroleum and natural gas accounted for more than 60% of total energy consumption by that time. This increased penetration coupled with a larger energy market led to an increase of production of oil by a factor of more than 4 and of natural gas by more than 5.

This stupendous rise of liquid and gaseous fuels was, to a large extent, based on low pricing policies made possible by the development and exploitation of extremely large low cost reserves in the Middle East and later in North Africa. The happy period when the prices of liquid fuel were, in fact, decreasing in real terms came to an end at the beginning of the 1970's when a combination of political, commercial and social factors led to what is currently called the energy crisis but which is, in fact, a discontinuous jump in energy prices. Middle Eastern oil, which had been the price leader on the down side for most of all other fuels has now become the price leader of the upswing, and the ultimate cost of fossil fuels will be determined by that of available substitutes.

The Short-Term Prospects (1974 - 1985)

Over this period, during which major changes in the market shares of different fuels cannot be expected to occur because of the lead times involved for the development and commercialization of radically new sources of power, the price of liquid fuels and those of gas are likely to be determined by political and commercial confrontations with wide fluctuations around a generally upward trend. The position of the bargaining

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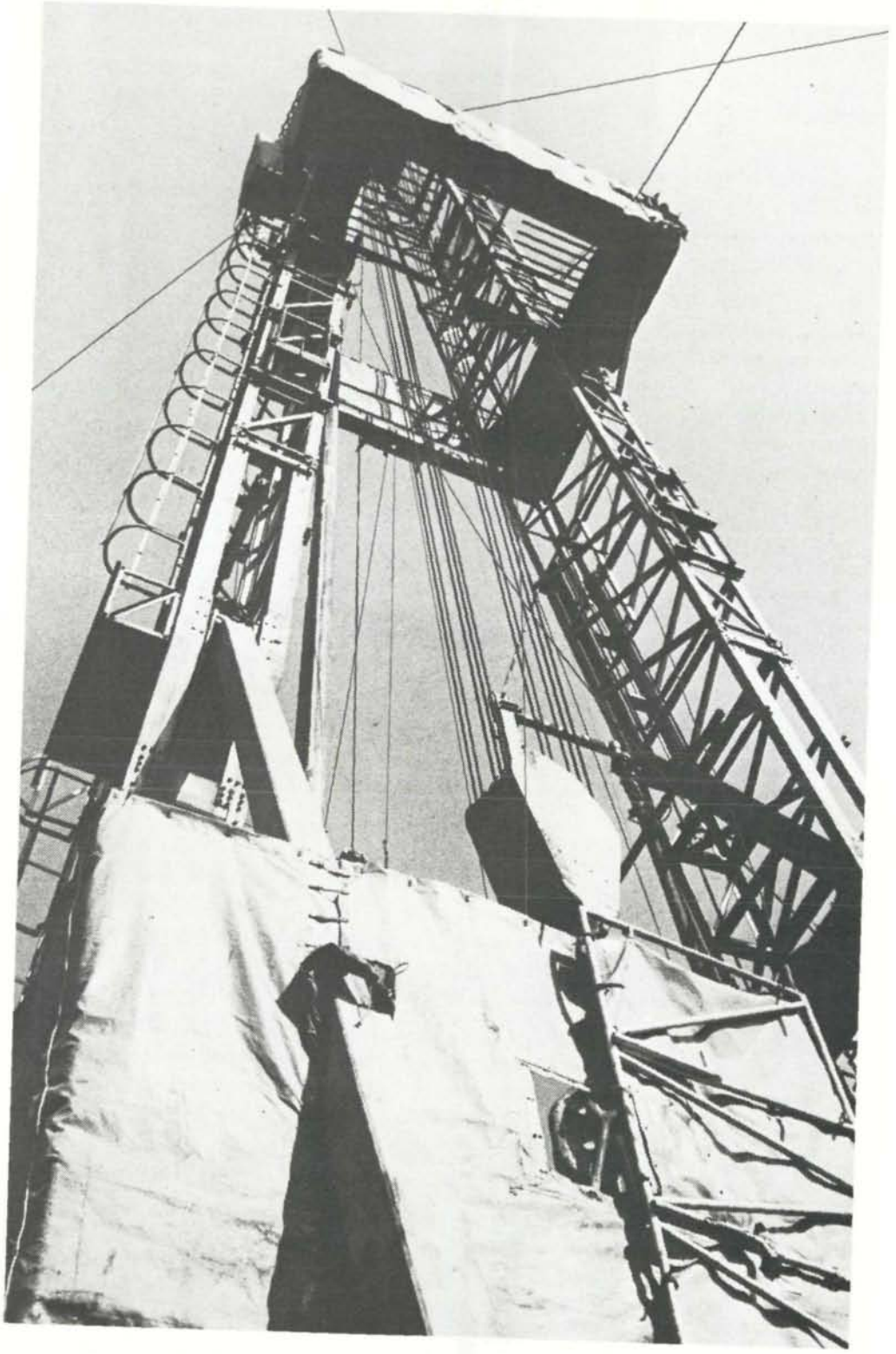
An oil rig reaching into the skies. The changing price of this product is causing concern in the world energy market ..... O.M.V. ▶



partners are fundamentally different, with most of the Middle Eastern oil producers capable of taking an interruption of oil revenues easily in their stride, while the industrial countries would find any lengthy cut-off of oil supplies unbearable for their normal industrial operations. The degree of probable dependence on Persian Gulf and North African oil is illustrated by **Tables 4 and 5.**

The only immediate factors which may exercise some dampening effect on rising fuel prices will be the substitution of coal for oil and for gas in electric power plants, and increased offshore production in new areas and at deeper levels. Both types of action involve additional costs.

The share of nuclear power, which is expected to exceed 10% of total primary energy by 1985 (see **Tables 2 and 3**) only slightly, would seem to indicate that its role as a potential short-term substitute is relatively limited. This, however, does not imply that its future prospects would not influence prices of fossil fuels. Pricing policies for oil and gas will take into account not only *existing* nuclear power plants, but also the *size and credibility of future programmes* so that medium term prospects may influence the actual prices of energy in the short term.

The Long-Term Prospects (1985 - 2000)

As seen from **Table 3,** nuclear fuels are still not expected to be the major source of energy by the year 2000 when they will represent less than 28% of the total, while natural gas and oil would still account for more than 48%. Even if this situation were to be considered tentatively as acceptable, a credible effort should be made to indicate that it is open to alterations, especially through an increased penetration of nuclear energy. Such an expansion of the share of nuclear energy by the turn of the century could be achieved through a series of ways:

a) An increase in the share of nuclear power in total electric energy, which would require operation of many nuclear stations in the modulated part of the load diagram.

b) An increase of the share of electric energy in total energy which would call for the development of individual and collective electric transportation as well as that of commercial and electric heating. It might be noted in passing that the efficiency of energy use in the electric car and the heat pump may be such as to offset the loss of waste heat at the power plant level, thus improving the overall efficiency of energy utilization.

c) The development of applications of nuclear heat to industrial processes and the use of waste heat of nuclear power stations for desalting and urban heating. The first possibility calls for increased attention to high temperature reactors. The second to the problem of urban siting of nuclear stations.

Apart from research and development efforts, such possible developments require a solid resources base and must initially rest on the assumption of continued availability of nuclear fuels. **Table 6** gives a very general estimate of world energy resources and although it should be viewed very cautiously as, indeed, any table containing figures for resources without a clear indication of the advancement of prospecting work and of the costs of recovery of the ores, it clearly points out certain conclusions. If known low-cost uranium were used in present light water reactors only, it might meet the requirements of

the present programmes for nuclear power roughly to the end of the century. If used in breeders, resources would be multiplied by two or three orders of magnitude and exceed those of all fossil fuels combined. Clearly, a long-term credible programme for meeting world energy needs through nuclear fission must rest on breeders or near-breeders.

Little has been said about the competitive status of nuclear power. The reason for this omission lies in the fact that nuclear electricity is already competitive on the basis of present fossil fuel prices of 40 to 50 cents per 10^6 BTU's. The previous argument points to a rate of rise of these prices exceeding that of general inflation. A differential rise of 2% to 4% represents a likely range. Hence, the penetration of nuclear energy will be limited not by immediate economic constraints, but by a series of problems inherent in the rise of a radically new technology such as: safety and environmental constraints, waste disposal problems, optimal use of resources over time, avoidance of the wide short-term price fluctuations which have so frequently occurred for other fuels in the past, development of new applications of electricity and of nuclear heat, efficient prospecting policies for uranium and, last but not least, public educational efforts. The International Atomic Energy Agency intends to expand its activities in every one of these fields.

TABLE 1. POPULATION AND USE OF PRIMARY ENERGY (Past and Projected)

	1950	1960	1970	1980	1990	2000
	Population (10^9)					
	2.50	3.00	3.60	4.35	5.20	6.10
	Use of Primary Energy (10^9 T.C.E.)[1]					
Solid Fuels	1.57	2.20	2.42	2.90	3.75	5.00
Liquid Fuels[2]	0.64	1.32	2.85	5.00	8.00	10.00
Natural Gas[3]	0.27	0.63	1.43	2.40	3.00	4.00
Hydro[4]	0.12	0.25	0.47	0.70	1.10	2.00
Nuclear[5]	-	-	0.03	0.80	3.15	8.00
Total Primary Energy	2.60	4.40	7.20	11.80	19.00	29.00

[1] 1 T.C.E. (Ton Coal Equivalent) = 7×10^6 kcal.

[2] 1 T of Liquid Fuel = 1.3 T.C.E. = 9.1×10^6 kcal.

[3] 1000 m^3 Natural Gas = 1.33 T.C.E. = 9.31×10^6 kcal.

[4] 1 kWh hydro was assumed to be equivalent to 2577 kcal throughout.

[5] 1 kWh nuclear was assumed to be equivalent to 2577 kcal for the 1970-90 period and to 2360 kcal on the average for the 1990 - 2000 period when breeders and HTR's with higher efficiencies may play a major role.

TABLE 2.

II
ELECTRIC POWER
(Past and Projected)

	1950	1960	1970	1980	1990	2000
Installed capacity (10^9 kW)		0.542	1.1	2.3	4.5	8.9
Energy production (10^{12} kWh)		2.24	4.9	10.2	20	39.6
Equivalent primary energy (10^9 T.C.E.)		0.82	1.8	3.7	7.4	14.6
Share of electricity in total energy (5)		18.7	25	31.4	39	50.3

III
NUCLEAR POWER

Installed capacity (10^9 kW)	-	-	0.02	0.31	1.3	3.3
Energy production (10^{12} kWh)	-	-	<0.1	2.2	9.1	22
Share of total electric energy (%)	-	-	<2	21	45	55
Share of total primary energy (%)	-	-	<0.5	6.6	17.5	27.7

TABLE 3. RELATIVE SHARES OF PRIMARY FUELS
ACTUAL AND PROJECTED (%)

	1950	1960	1970	1980	1990	2000
Solid Fuels	60.4	50	33.6	24.6	19.7	17.2
Liquid Fuels	24.6	30	39.6	42.4	42.1	34.5
Natural Gas	10.4	14.3	19.9	20.3	15.8	13.8
Hydro	4.6	5.7	6.5	6	5.8	6.9
Nuclear	-	-	0.4	6.7	16.6	27.6

TABLE 4. NATIONAL PRODUCTION AND IMPORTS OF OIL IN 3 MAIN CONSUMING AREAS (Millions of Tons)

	National Production		Total Imports		Imports from Middle East	
	1970	1980	1970	1980	1970	1980
USA	534	660	214	500	30	300
(% of consumption)	(71)	(57)	(29)	(43)	(6)	(26)
Western Europe	16	160	584	820	300	600
(% of consumption)	(2.6)	(24)	(97.4)	(76)	(50)	(61)
Japan	1	2	199	398	170	300
(% of consumption)	(0.5)	(0.5)	(99.5)	(99.5)	(85)	(75)
TOTAL	551	822	987	1718	500	1200

TABLE 5. PAST AND ESTIMATED PRODUCTION IN MAJOR EXPORTING AREAS (Millions of Tons)

	1970	Share of World Consumption (%)	1980	Share of World Consumption (%)
Middle East	714	31.6	1500	39.3
Africa	274	12	330	8.6
Caribbean	212	9.3	220	6
TOTAL	1190	52.6	2050	54

TABLE 6. ESTIMATES OF WORLD ENERGY RESOURCES (10^9 T.C.E. at 7×10^6 kcal per T.C.E.)

Solid Fuels	1,000 - 10,000
Oil (including shale oil and tar sands)	100 - 1,000
Natural Gas	40 - 400
Uranium	
a) If used in light water reactors (Recovery Costs $<$ \$15/lb U_3O_8)	60 - 90
b) If used in breeders in the same ore cost range	5,000 - 7,500
c) If used in breeders* with ore recovery costs up to \$100/lb U_3O_8	50,000 - 75,000

* This range of resources is given as an indication and not comparable with other cost figures.