Energy Choices That Europe Faces: A European View of Energy

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Demand and Supply of Primary Energy

Up to the middle of the 1950's domestic coal was available in sufficient quantities for a number of European countries (such as Germany, England, Belgium) to make them self-reliant in energy. After the second world war the low prices of oil, the increasingly open market, and a certain aging of the coal industry together with the comparatively extreme working conditions prevalent in coal mining resulted in a major change. Since the end of the 1950's, oil has conquered an ever increasing share of the expanding primary energy market in the booming economies of Western Europe and elsewhere.

The relevant data on the primary energy needs in the Federal Republic of Germany are shown in Table 1. The share of coal has fallen from roughly 70 percent in 1957 to a value as low as 23 percent in 1972, while the share of oil has risen from 11 to 56 percent. The absolute figures show a less dramatic decrease, which is nevertheless severe. The share of oil in the Community of the Six is even higher. It was at 65 percent in 1970, while the corresponding figure for the United States was 43 percent. The important points is that in the United States only about one-third of that oil is imported (or 14 percent of the total energy demand), while in Europe practically all the oil is imported. This observation reveals a first and basic difference between the energy situation in the United States and Europe.

Table 2 gives the consumption in kilowatts per capita in various European countries as compared to that of the United States. While the per capita consumption in Europe at present is 40 percent of that of the United States, it is expected to increase to 60 percent by 1985. By and large this gives a factor of 2 between the United States and Western Europe and establishes a second difference between the energy situation in the United States and Europe. However, the gross domestic product (GDP) per capita in Western Europe is much closer to that of the United States than is indicated by the ratio of the per capita energy consumption. It is also interesting to consider the use of such primary energy. Figures 1 and 2 indicate the shares of the various uses of energy in the United States and Germany.

Limited Oil from the Middle East and Substitution by Coal

It has been estimated that the amount of crude oil in the Middle East is 350×10^9 barrels or 2 Q ($1\ Q = 10^{18}$ Btu). If 430 million people (all of Western Europe plus Japan) at 10 kilowatts per capita use oil to make up two-thirds of that amount, 0.09 Q per year would be required. The reserves of the Middle East would then last for about 23 years. With U.S. participation in the harvesting of these reserves the period would be shorter. Although the actual period that these reserves might last will be somewhat different, the estimate of 23 years is indicative. A. Khene, Secretary-General of the Organization of the Oil Exporting Countries, observed (*1*) that such a period is too short for the countries of the Middle East. They must make use of their natural wealth for a significantly longer period. Khene therefore concludes that the oil price must be raised to a level that allows other primary energy sources to enter the scene and thereby to alleviate the oil supply situation.

Coal reserves are about 15 times, as a global average, larger than oil reserves (*2*). Therefore, the natural substitute for oil is coal. However, in making the substitution, we must realize that geographical differences in coal reserves are large. The United States appears to have an unusually large proportion of the total amount of coal, while Europe does not.

The data in Table 3 are based on a consumption rate of 10 kilowatts per capita. The 37 Q of the United States therefore should last for more than 600 years if all 10 kilowatts were provided by coal. This figure and the others in Table 3 are merely indicative; the actual figures cannot be predicted easily. Europe's main coal reserves are located in Germany and England. If these reserves were consumed by all countries of Western Europe, a time span of only 36 years would result—which would be in sharp contrast to the U.S. figure. If Germany alone consumes all of its available coal it would be enough for 160 years. The figures become less threatening if coal reserves at depths greater than 1200 meters are considered. These are given in Table 3 in parentheses. As a contrast to coal, Table 3 also shows the figures for domestic oil and gas. It is obvious that these domestic oil and gas resources are of significant usefulness for a much shorter time period only—or for a much smaller portion of the supply of the primary energy. It is therefore only natural for the United States to prepare for the large-scale use of coal (*3*).

The question arises as to whether nuclear energy can reduce the extent of coal use. One has to realize that nuclear power has been developed as a means of providing electricity that is competitive with (artificially) cheap fossil fuels [50 cents per million Btu (1 Btu = 1.06×10^3 joules) or less]. At the same time, the development of nuclear power was intended to act as a technological innovator, rather than to solve an early energy crisis. As a result, during the current energy crisis, nuclear power can at best take care of that portion of primary energy which goes into the production of electricity. At present this is at 25 percent in Europe and 20 percent in the United States, but it is expected to steadily increase to provide as much as 40 percent or more, because of the annual

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increase of 8 percent in electricity consumption as compared to that of 4.5 percent for primary energy. In any event, we can try to ease the transition from oil to coal by shifting the production of electricity to nuclear power insofar as possible.

The government of the Federal Republic of Germany has recently announced an energy plan for the years up to 1985. In Germany, nuclear energy is expected to take care of 15 percent of the primary energy demand, that is, 45 gigawatts of electricity. Similar percentage figures have been given for the United States. But in contrast to the United States, it will be difficult to raise the coal production in Europe: Most of the miners are gone (Table 4). The German coal production is now down from 141 million tons (metric) in 1962 to 102 million tons in 1972. The productivity per miner per shift has risen from 2.4 to 4 tons, and therefore the number of employees in the coal industry is down from 434,000 to 221,000. The figure for employees actually engaged in mining is still smaller. It has been estimated that it will be virtually impossible to raise the coal production to more than the original 140 million tons per year. In contrast, to satisfy present coal uses and to substitute for oil as a primary energy source would, in 1985, require 380 million tons of coal in the case of the Federal Republic of Germany alone. Of these 380 million tons, 330 would be for the substitution of oil by synthetic fuels, while only 50 million tons would be for genuine coal consumption. If it becomes necessary for the relatively coal-rich Germany to provide other European countries with coal, the coal production required would be higher, making it obligatory to go to mining depths greater than 1200 meters. The more restricted and cumbersome situation of coal mining in Europe at a scale that could alleviate the oil supply basically differs from the respective situation in the United States, and this is another very significant difference between the energy situation in the United States and Europe. Undoubtedly there is a strong incentive to look into new coal mining technologies. It remains to be seen to what extent it can be successful.

Table 1. Annual demand (as percent of total) for primary energy for the Federal Republic of Germany. [Source: "Das Energieprogramm der Bundesregierung," Report of the Bundesministerium für Wirtschaft, Federal Republic of Germany, Bonn, 1973]

Source	1957	1967	1972
Oil	11.0	47.7	55.4
Coal	69.9	36.2	23.6
Lignite	14.8	10.2	8.7
Gas	0.3	2.1	8.6
Nuclear		0.2	0.9
Others	4.0	3.6	2.8
Total	100.0	100.0	100.0
$\triangleq 10^{6}$ mtce/yr*	198	271	362
$\triangleq$ Q/yr	0.0054	0.0074	0.0099

* 1 Q $\equiv 10^{18}$ Btu $\triangleq 2.93 \times 10^{04}$ kilowatt-hours $\triangleq 2.52 \times 10^{17}$ kcal $\triangleq 3.6625 \times 10^{00}$ metric to coal equivalents (mtce).

Three Phases of the Energy Problem

It has been indicated that the global resources of fossil fuel are about 200 Q (*2*). With 10^{10} people and 10 kilowatts per capita this gives a period of only 66 years before these resources are used up. Of course, reality is more complex and actual figures would be different but it is possible to draw one simple conclusion from this little calculation: In a not too distant future we will have to live with an energy supply that comes from nonfossil fuel resources.

There are four options for such nonfossil energy supply (*4*): (i) nuclear fission in the fast breeder and other reactors; (ii) nuclear fusion; (iii) solar power; and (iv) harvesting of the heat of the earth crust (geothermal in the general sense). Both the fast breeder and the fusion breeder, which is based on the (d,t) reaction, give energies that are sufficient for about 10^6 years with no qualitative difference between these two options except that the fast breeder is already technically feasible. This observation is in contradiction to a widespread belief, and I would like to refer to an article which elaborates on that issue in greater detail (*5*). The options of solar and geothermal energy must be explored more thoroughly before it will be possible to make assessments.

Although it must be borne in mind that eventually there could be more than one option for the long range

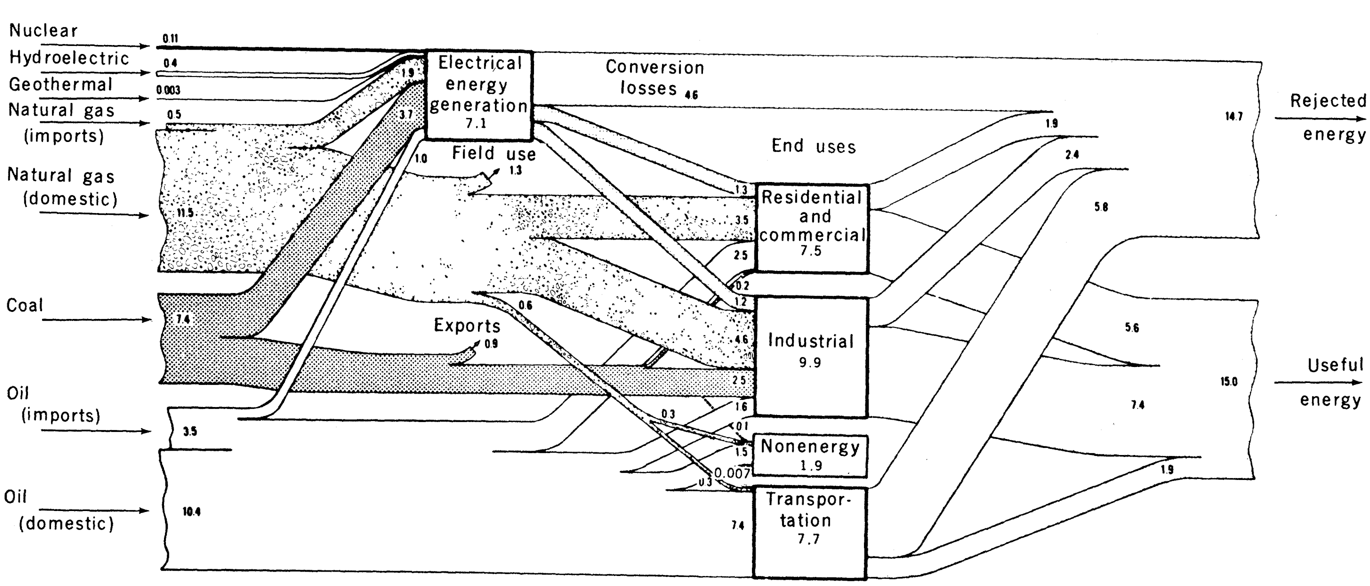

Fig. 1. Total energy flow pattern in the United States 1970. Units are in millions of barrels of oil equivalent per day. (1 ton coal equivalent per year = 0.01312 barrels of oil equivalent per day). [Source: Joint Committee on Atomic Energy, Certain Background Information for Consideration When Evaluating the "National Energy Dilemma," U.S. Government Printing Office, Washington, D.C. (1973)]

Table 2. Consumption of energy (as kilowatt per capita) in Europe and the United States. [Source: "Prospects of primary energy demand in the community (1975–1980–1985)," Commission for the European Communities, 4 October 1972]

Country	1970	1975	1980	1985
Belgium	5.6	7.3	9.0	10.7
France	3.9	4.8	6.1	7.7
Federal Republic of Germany	5.1	6.3	7.8	9.8
Italy	2.7	3.7	4.7	6.1
Netherlands	4.9	6.8	8.5	10.4
Average in the European Community of the Six*	4.4	5.8	7.2	8.9
United States	10.9	12.3	13.7	15.2
European Communities/ United States	0.404	0.472	0.526	0.586

* The dates of the United Kingdom fit into the here extended pattern of energy consumption.

supply, nuclear fission, must now be examined further since it is the only viable option today. As mentioned earlier, nuclear power has been developed for the competitive production of electricity only. If electricity's share is not more than 40 to 50 percent, how can nuclear fission be the source of all the primary energy demand? The answer is: By reactors that provide process heat at high temperatures. The incentive to develop such reactors now turns out to be larger than the incentive to develop and operate reactors for the production of electricity. Fortunately, the United States has the high temperature gas cooled reactor (HTGR), which has been developed by the Oak Ridge National Laboratory and the Gulf General Atomic Company. In Germany there is the high temperature pebble bed reactor, which has been developed by the Kernforschungsanlage Jülich and Brown Boveri Company at Mannheim. In the long run the most convincing scheme for the use of nuclear process heat is the splitting of the water molecule with the result that hydrogen would be used on a truly large scale. Hydrogen would then complement electricity as another secondary fuel. Much attention has already been given to this long range option (*6*).

Gulf General Atomic (*7*) and the Kernforschungszentrum Karlsruhe, Germany, have considered using the breeding gain of fast breeder reactors for providing the necessary ^{233}U fuel for the high temperature gas cooled reactors. In such a scheme, where energy consumption has leveled off, all of the secondary energy in the form of electricity would be produced by fast breeders; at the same time all of the secondary energy in the form of hydrogen would be produced by high temperature gas cooled reactors that are fueled by the breeding gain of fast breeders. More detailed investigations indicate that in such a scheme the ratio between secondary energy in the form of hydrogen and secondary energy in the form of electricity, for example, could be 3 : 2, which generally fits with market requirements. Figure 3 illustrates such an asymptotic integrated reactor scheme, with the abundant isotopes ^{238}U and ^{232}Th being the only input. The transition periods into such an asymptotic scheme have already been evaluated (*8*). A model consisted of a community of 250 million people, which would grow to 350 million within 40 years, and which then would remain constant. It was assumed that the share of primary energy devoted to the production of electricity was 25 percent at the beginning and would increase to 50 percent. At first, nuclear reactors were installed; these were light water reactors (LWR) built to increase the capacity by 18 gigawatts of electricity per year. After 18 years, the yearly plutonium output

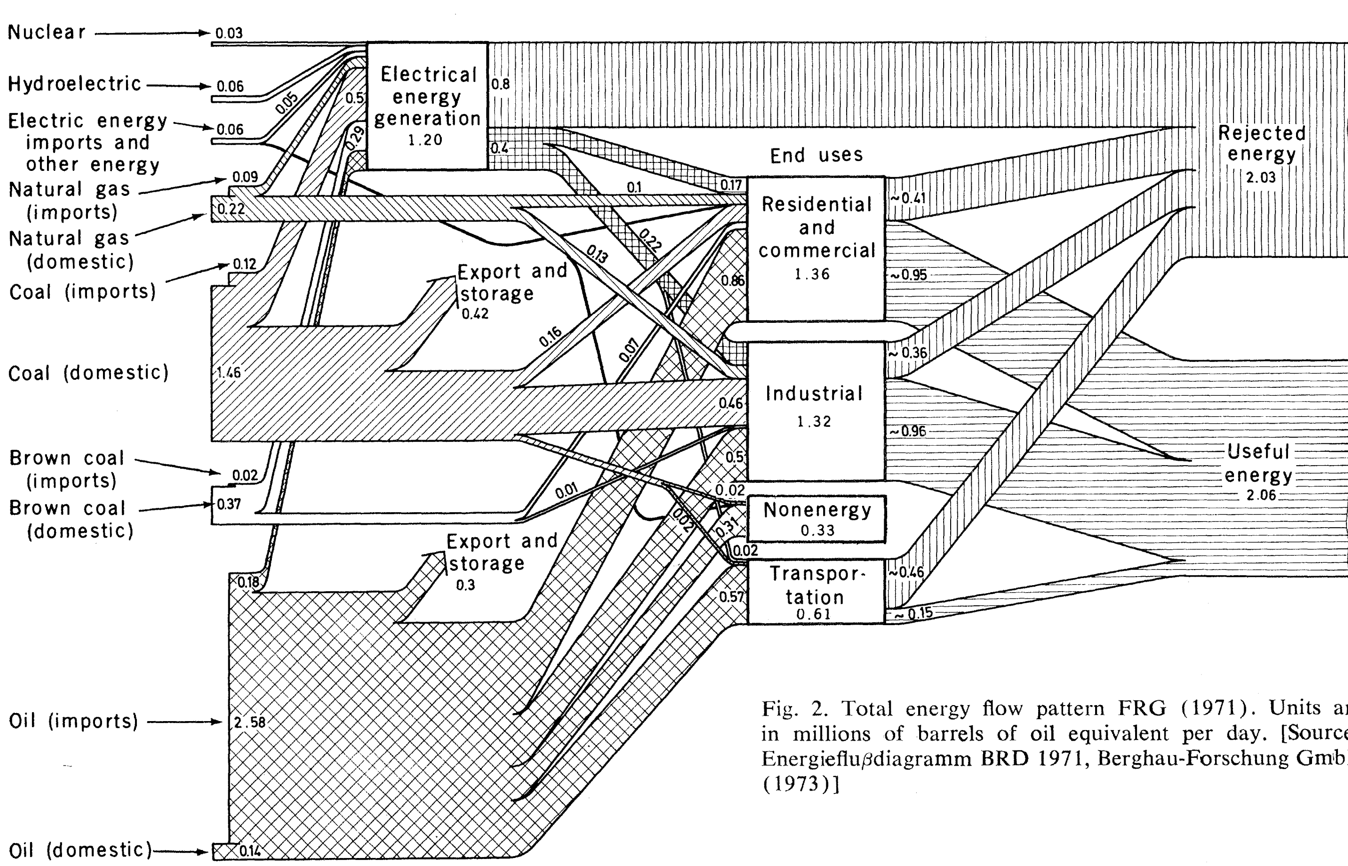

Fig. 2. Total energy flow pattern FRG (1971). Units are in millions of barrels of oil equivalent per day. [Source: Energieflußdiagramm BRD 1971, Berghau-Forschung GmbH (1973)]

of these LWR's becomes large enough to provide the plutonium inventories of fast breeder reactors (FBR), which were built at the same rate of 18 gigawatts per year. The FBR's are then assumed to replace the LWR's after 18 years. At the same time the installation of HTGR for the production of hydrogen becomes possible. Further, 18 gigawatts of electricity correspond to 45 gigawatts of heat, and because of the coupling of ^{233}U (production in FBR's and consumptions in HTGR), a rate of introduction of HTGR's of 45 gigawatts of heat per year is assumed.

The installation of FBR's and HTGR's would continue until all of the primary energy demand has been met and all LWR's have been replaced by FBR's. Until that time fossil fuel and cheap uranium for feeding the LWR's with ^{235}U are required. It should be noted that in such a scheme FBR's act as a final waste box for all the plutonium produced by the limited generation of LWR's; and that at the same time FBR's produce the necessary electricity and the necessary ^{233}U that allows for the production of hydrogen. In this radically different use of the virtues of fast breeders, no doubling of any kind has been taking place. A few of the results obtained so far are given in Table 5. Most important is that at the construction capacity considered here it takes 60 years to master the transition from today's situation into an all-nuclear energy economy. With significantly higher construction capacities, this period could be shorter. To master the transition, 3 Q of fossil fuel is required. The model society described above corresponds roughly to conditions in Europe. Fortunately the required 3 Q matches the genuine European coal reserves, as shown in Table 3. Within the constraints of the model employed here the major conclusion is that for European conditions the envisaged new coal era can last about 60 years or so if all this coal is to be burned. Further, the United States does not differ greatly from this model society. But U.S. coal reserves are larger by an order of magnitude if all U.S. coal is to be burned within the United States. Under these conditions the relevant transition period would be much longer. However, whether all U.S. coal should be consumed domestically is a question for review. Table 5 points to the relatively large consumption of cheap uranium during the transition period. Therefore the supply

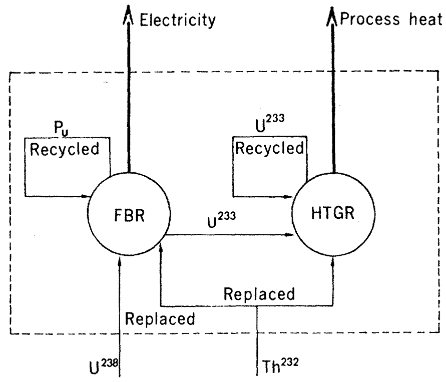

Fig. 3. Asymptotic integrated power reactor system. [Source: reference (*8*)]

of cheap uranium could become a concern sooner than could the supply of coal. Evaluation of this scheme is continuing (*9*).

Here it must be emphasized that the coupling of FBR and HTGR is not meant to be the only scheme of interest. The potential of the heavy water reactor, the possibility of producing hydrogen by electrolysis, the option of fueling HTGR's with plutonium, and many others have to be taken into account. The discussion in this article is primarily meant to introduce a new general possibility.

Against this background of an asymptotic phase for the provision of energy on a nonfossil basis, the new uses of coal are obvious signs of a transition period, which requires, in itself, major technological preparations and change. Until such technological changes can become effective some time will elapse, and this interval characterizes the near term phase of the energy problem. Table 6 identifies these three phases of the energy problem.

Timing and the evaluation of the transition—for instance by systems analysis—turn out to be the principal

Table 3. Coal, lignite, and oil reserves in Western Europe and the United States, and periods for these reserves to last. [Source: Figures derived from data of the *Statistical Yearbook of the United Nations*, New York, 1973]

Item	F.R. Germany	Western Europe	United States
Coal and lignite reserves (Q)	2.92 (+ 4.37)*	3.50 (+ 4.37)*	36.69
Oil and natural gas reserves (Q)	0.017	0.214	0.469†
Annual consumption for 10 kw/capita (Q/yr)	0.018	0.098	0.061
Period of time, if coal (yr)	160 (+ 238)	36 (+ 44)	602
Oil and natural gas exclusively (yr)‡	0.9	2.2	7.7

* Reserves in depths below 1200 m, the use of which today is not feasible economically and sociologically. † Tar sands and shale oil not included. ‡ No population growth assumed.

Table 4. Coal production in the Federal Republic of Germany. [Source: "Das Energieprogramm der Bundesregierung," Report of the Bundesministerium für Wirtschaft, Federal Republic of Germany, Bonn, 1973]

Item	1962	1964	1966	1968	1970	1972
Coal production (10^6 metric tons)	141.1	142.2	126.0	112.0	111.3	102.5
Total number of miners (thousands)	434	399	334	364	250	331
Coal per miner per shift (metric tons)	2.37	2.61	2.93	3.53	3.76	4.02

Table 5. Transition into an all nuclear energy supply for a model society. The data are based on the assumption of a model society with 250×10^6 people at the start ($t = 0$) and 360×10^6 people 40 years later, the rate being 10 kilowatts per capita in the asymptotic state.

Item	Unit
(i) Reactor construction capacity	18 gigawatts of electricity per year (LWR or FBR for electricity generation)
(ii) As (i), and in addition after 18 years	45 gigawatts of heat per year (HTGR for process heat generation)
(iii) Length of transition period—time until total reliance on nuclear energy is achieved	≈ 60 years
(iv) Total energy consumption during transition period	≈ 6 Q
(v) Amount of fossil fuel required during transition period	≈ 3 Q
(vi) Amount of cheap natural uranium required during transition period	≈ 3.10^6 tons

Table 6. The three phases of the energy problem.

Characteristics	Dates	
	Beginning	End
	Asymptotic phase	
Based on nuclear fission, fusion, solar, geothermal power, or a combination	2050 in Europe 2200 in the U.S.	To forever?
	Transition phase	
Based on the substitution of oil by coal and on nuclear energy for the production of electricity	1985	2050 in Europe 2200 in U.S. (??)
	Near term phase	
Characterized by the administration of fuel shortages and the preparations for the transition phase	1973	1990

points of attention in the energy problem. It is therefore advisable for the various research and development activities to be compatible with each other and with the timing of the problem. And the fairly important differences between the European and the U.S. situation can best be identified by emphasis on the different timing. Europe has much less time to master the transition into the asymptotic phase.

It is against this background that I now turn to problems of secondary energy.

Secondary Energy

As was observed earlier, 75 percent of the primary energy in Europe today is devoted to nonelectrical purposes. About 55 percent goes to stationary applications, while about 20 percent goes to transportation. In Germany Schulten conceived and promoted the idea of the pebble bed reactor (*10*), with a random package of balls of about 5 cm diameter making up the core. The fuel elements are balls and not rods. With appropriate fuel management [the OTTO (once through then out) scheme (*11*)], this pebble bed reactor is particularly well suited to high temperatures. On 27 February 1974, the Jülich AVR experimental reactor for the first time reached an outlet temperature of 950°C, thus providing heat for many chemical applications. Schulten and his co-workers have now proposed to employ such nuclear process heat for transformation into chemical binding energy. The splitting of the water molecule in three or more chemical stages as proposed by C. Marchetti and co-workers (*12*) is only one, but very promising, scheme for such a transformation into chemical binding energy. A more typical near term application would, for instance, be the application of nuclear process heat to the well-known chemical reaction

$$CH_4 + H_2O + 49\ \text{kcal/mole} \rightleftarrows 3H_2 + CO$$

The procedure for such an application is shown in Fig. 4. Methane with the appropriate amount of water is transformed into hydrogen and carbon monoxide by nuclear process heat. In a heat exchanger these gases are cooled off and as cold gases can be transported over any distance. On the consumer side they are led to react and give away their chemical binding energy.

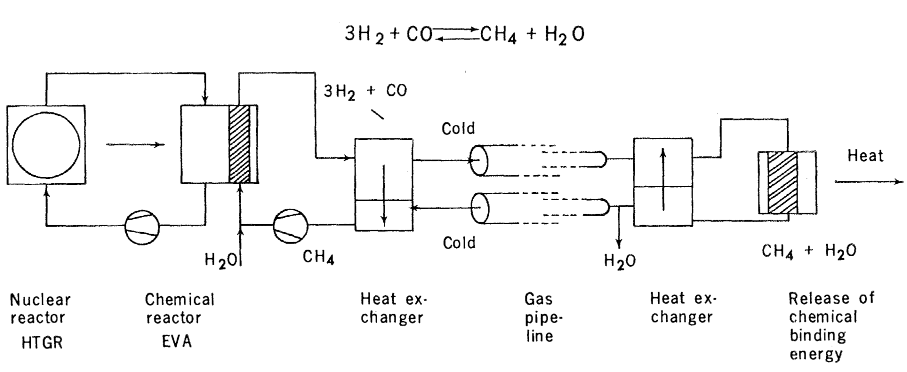

Fig. 4. Energy transmission system EVA + ADAM. [Source: reference (*13*); courtesy of KFA Julich, Germany]

Methane is transported back to the power station. The chemical reactor for the production of hydrogen and carbon monoxide is called EVA (Einzelsphaltrohrversuchsanlage), and its counterpart is called ADAM, of course. ADAM is the burner of the gaseous fuel (*13*). The advantages of this or similar schemes are remarkable:

1) Process heat can be transported over any distance. This allows central nuclear power stations to play the role of a natural gas field far away from applications.

2) The reaction cycle is a closed one (one may send back the water if so desired). The implication is that the environment remains completely untouched by pollutants or by CO_2 which always results if coal or other fossil fuels are burnt and which may also have adverse effects (*14*).

3) Apart from losses no material other than nuclear fuel is consumed. No fossil fuel except for producing the initial inventory of the pipes is required.

4) It employs technology that is basically available already.

At the Kernforschungsanlage (KFA) Jülich the demonstration of that scheme over a distance of a few miles and in the megawatt range is being prepared. The consequence, of course, would be the installation of a widespread pipeline system that uses more than one single pipe at a time. In fact, a pipeline must contain two subpipes: one for hydrogen plus carbon monoxide and the other for methane. This is somewhat in parallel with electrical transmission lines. In both cases there are two (or more) conduits.

As before, I do not mean to say that it is specifically the production of hydrogen and carbon monoxide which is the solution to all problems. There may be more suitable chemical reactions. Again my point is to introduce a new general possibility.

I consider the development of a scheme like EVA and ADAM and its installation together with the installation of appropriate central power stations for nuclear process heat to be among the main energy tasks in Europe. It serves both for the transition phase and the asymptotic phase as described in Table 6. The energy costs for the EVA and ADAM scheme are estimated to be $2 per million Btu for the consumer. Let us consider this an indication of the relevant range of energy prices. It is equivalent to an oil price of $12 per barrel (to the consumer) and is now comparable to prices on the present oil market. Against this background it is interesting to look at the already existing pipeline system for gases in Europe.

Figure 5 is a map of the existing European pipelines for gases—already a fairly tight system. On the basis of \$400,000 per kilometer for pipelines larger than 50 centimeters and \$240,000 per kilometer for pipelines smaller than 50 centimeters, the investment costs for the existing pipeline system have been estimated to be about \$15 billion. To establish a more extended modern pipeline system may cost something like \$200 billion. To put this figure into perspective it is worthwhile to consider the present cost of the energy transmitted by that modern pipeline system. At 5 kilowatts of heat per capita and 327 million people with \$2 per million Btu, one arrives at the linear value of $\$10^{11}$ per year; at a discount rate of 15 percent, the present value would be about \$700 billion. In view of these numbers and of the global energy challenge an investment of \$200 billion, large as it is, appears acceptable, especially because it would be spread over at least 10 years. For 327 million people this amounts to \$60 per year per person over a period of 10 years. But this is not the only expenditure. The central power plants and other devices must also be built. Nevertheless, this above sum indicates the order of magnitude of what is at stake. I intentionally refrain from elaborating on the question of whether a market mechanism alone can bring this change about and to what extent an emergency type venture must be envisaged.

The above discussion deals with process heat for stationary applications —what about transport?

The answer is to make use of coal for synthesizing hydrocarbons. Methanol seems to be a promising fuel (*15*). Its heat content is 170.9 kilocalories per mole, that of carbon is 94 kilocalories per mole. The ratio between these two is 1.8 or, in other words, the value of carbon as a fuel can be multiplied by the factor of 1.8 if the difference in chemical binding energy is supplied by a nonfossil fuel source. I refer, of course, to nuclear process heat. If 20 percent of the primary energy demand is for transportation this means in effect that only 11 percent need be taken over by carbon as a source of primary energy. Other chemicals should be considered also —particularly, methane—whose lower weight makes it feasible for aviation purposes. Methane produced from coal with nuclear heat increases the fuel value of the carbon by a factor of 2.2. One must also continue to keep hydrogen in mind. Schulten and others have proposed that only this reduced percentage of coal designated for transportation purposes be used for burning. This would be indeed in sharp contrast to the situation in the United States where one envisages the burning of all coal resources. Under these circumstances European reserves would last for a period of perhaps 150 years. Here, too, my intention is to open up a general possibility.

In Europe all the components to master the energy problem are available: light water reactors, high temperature gas cooled reactors, the fast breeder, a little bit of coal, the technology for handling process heat as chemical binding energy, and the technology of pipelines and chemical engineering. If properly put together, these components could be a more or less

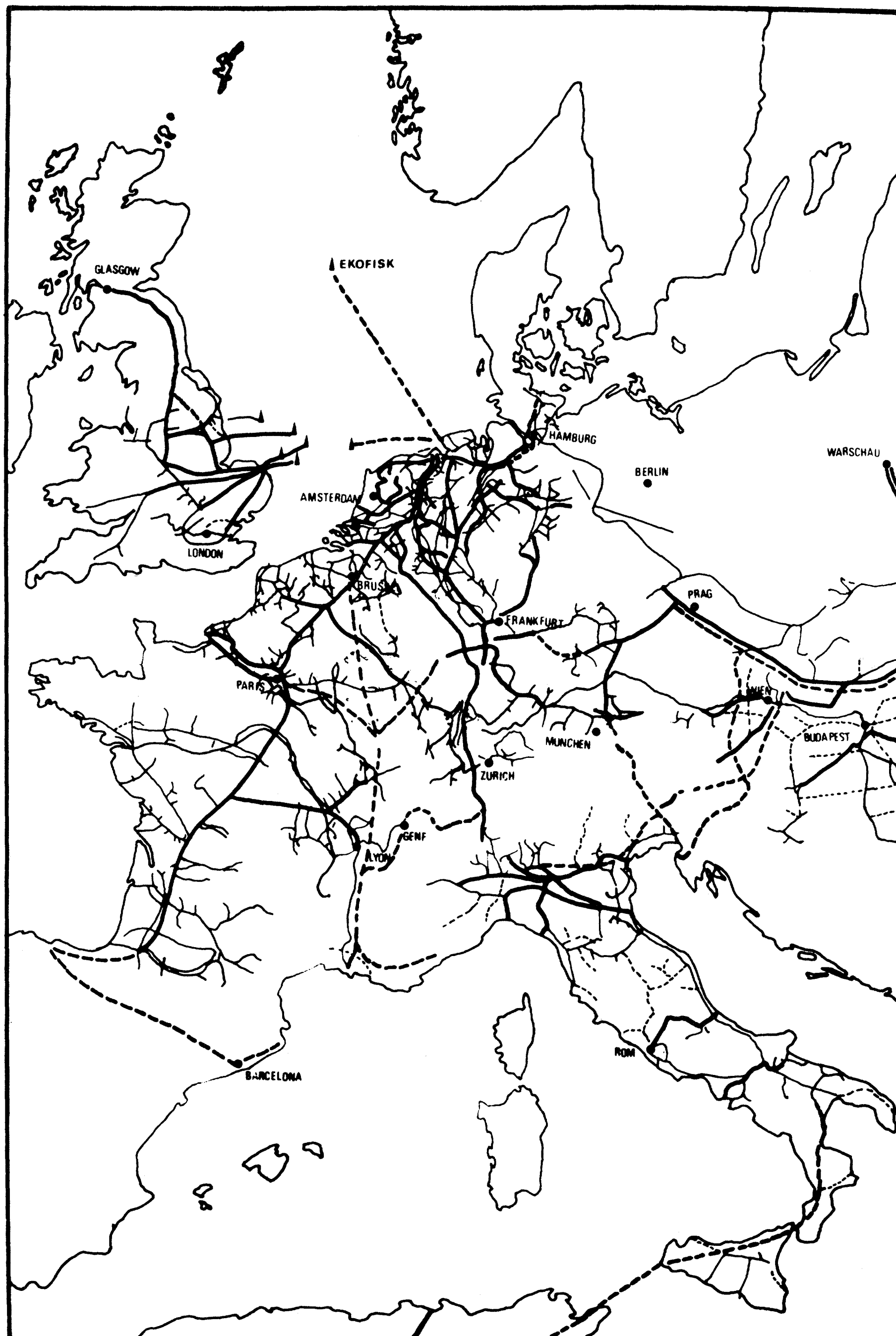

Fig. 5. Present natural gas pipeline system in Europe. [Source: Niedersächsisches Landesamt für Bodenforschung, Hannover; Jahrbuch für Bergbau, Energie, Mineralöl und Chemie, Verlag Glückauf GmbH, Essen (1973)]

final answer to the energy problem during the transition period. To a large extent this solution could reestablish Europe's "energy" self-reliance and could alleviate the oil situation.

Primary Energy Parks

A large and modern pipeline system tends to deemphasize the question of siting of large power plants that provide chemical process heat for the use in chemical reactors such as EVA. As was stated above, large central power plants could assume the function of natural gas fields. If so, we should examine the possibility of centralizing large electrical power plants. Such a project would require an extension of the electrical grid. The present European grid is already very extended and strongly interconnected. But one has to realize that the weighted average distance for the transport of electric power in Germany is only 100 kilometers. The existing high voltage lines serve to reduce standbys and the handling of peak loads. At 380 kilovolts they can transmit about 5 gigawatts over distances of 500 kilometers. An upgrading of technology into the domain of 10 to 50 gigawatts therefore is required. Ultra high voltage, direct current lines or superconducting cables (*16*) can probably do the job. In so doing the consistency with gases as the other form of secondary energy must be kept in mind and the entire infrastructure must be optimized.

A modern infrastructure for the handling of secondary energy, gases and electricity, tends to deemphasize the question of siting large power plants. This could be important in the long run. Let us consider, for example, the cooling water requirements for the production (conversion) of primary energy. If electricity assumes 50 percent of the primary energy production with a thermal efficiency of 0.4 and the other 50 percent of the primary energy production is for the production of chemical process heat at a thermal efficiency of 0.6, then out of 10 kilowatts per capita as much as 5 kilowatts per capita is waste heat at the sites where the secondary energies are to be produced. For a population of 3.27×10^8 Europeans, this leads to a total of 1.6×10^{12} watts of waste heat at the site of the power plants. Wet cooling towers permit the dissipation of 3×10^9 watts per cubic meter of water per second. Therefore 1.6×10^{12} watts requires 1.6×10^{10} cubic meters per year if that waste heat is to be dissipated in wet cooling towers. The rainfall in central Europe is at 0.8 meter per year, thus giving 0.8 cubic meter per year per square meter. Therefore 2×10^{10} square meters is required if all of the related rainfall be given to wet cooling towers. More realistically, if only 10 percent of all the rainfall, and that means 20 percent of all runoffs in rivers, creeks, and the like, were given to wet cooling towers, then an area of 500 by 500 kilometers would be required within which such collection of water had to take place. This crude calculation points to the difficult problem of interfaces between energy, water, the climate, and land use. This is a subject in its own right and cannot be covered in this article. It leads to the recognition of the fact that not only the production of energy is a problem, but increasingly it is also the embedding of energy in the atmosphere, the hydrosphere, the ecosphere, and the sociosphere which has to be considered (*4, 17*). I feel that such embedding will be the principal incentive for the energy technology of the asymptotic phase (*18*).

At present it appears that the concept of having large primary energy parks in the open sea could largely solve these problems of adequate energy embedding. The handling of waste heat in the open sea seems to be much less of a problem than on the continents. In case of nuclear power such primary energy parks should be large enough to embrace their own fuel cycle facilities, as has been proposed by A. M. Weinberg and R. P. Hammond (*19*). Many of the concerns about nuclear power could be eased in this way. If eventually solar power turns out to be a feasible source of energy, large areas will be required for the harvesting of solar energy. I feel that not more than 20 watts per square meter can be expected. If all of the primary energy demand of Europe were to be provided by solar power this would then require an area of 400 by 400 kilometers. Such a large area would best be found in the open sea; this immediately leads to problems of the Law of the Seas, but it is still consistent with the idea of large primary energy parks in the open sea.

The point is this: If Europe develops a modern secondary energy system, it deemphasizes not only the painful problem of siting power plants but also the problem of deciding early what kind of process for the conversion of primary energy into secondary energy should eventually be employed. I believe that nuclear fission and in particular the combination of FBR and HTGR will continue to play a dominant role. But if other options turn out better let us use them in primary energy parks. The continents would remain unaffected. Remarkably enough, such primary energy parks are already being developed in Europe. In Fig. 5 the pipelines are shown which connect the continent with floating platforms above the new (even though in the long run limited) gas fields of the North Sea. This suggests a later transformation of such platforms into energy parks.

Conclusion

In conclusion, I feel that the energy challenge, tough as it is, does not pose unsurmountable technological problems, even in Europe. At least in principle, the necessary technology is already there. This article is meant to make that statement plausible. It is not the intention to insist on certain ideas. It is important, however, to have a consistent approach, and this means to obey the timing of the problem. Therefore the most important aspect during the transition phase probably is the buildup of a modern secondary energy system. In the long run it will be energy embedding and not the production of energy which will be the principal driving force for the development, because in principle at least there is more than one option to provide almost unlimited amounts of energy. In order to meet the demand for an appropriate embedding of energy, the concept of primary energy parks in the open sea seems to be most promising.

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20. The data were compiled and the article was prepared for this issue in a very short time. It is for this reason that mainly tables referring to the German situation have been incorporated. This work would have been impossible without the assistance of a whole team. I thank in particular: R. Avenhaus, R. Patzak, Mrs. T. Koopmans, C. Marchetti, and M. Grenon, all at Laxenburg; D. Faude, W. Sassin, and G. Friede, all at Karlsruhe. I am also greatly indebted to Direktor S. Pirklbauer, Salzach-Kohlenbergbau Ges.m.b.H., Direktor W. Renner, Österr. Verbundgesellschaft, and Direktor W. Zauner, Österr. Mineralölverwaltung A.G., for providing me with important background data.

A Timetable for Expanded Energy Availability

Allen L. Hammond

How soon can more energy be made available? Where will it come from and what will each potential source actually contribute? How much energy will really be needed? In the guessing game now going on within the federal energy establishment and in various independent study efforts, the answers given to these questions vary considerably from person to person. They depend, among other things, on whether the discussion involves just the technical potential of a technology or a resource or whether the estimate also assumes favorable economic conditions and a new political consensus that would change the rules of the game. Nonetheless, a convergence of opinion is beginning to appear on some aspects of this country's probable energy future and the debate on points of disagreement is sharpening. I give here one view (my own) of that future, noting a few dissenting views on major issues.

A key point in what follows is the belief that, as Landsberg points out in the introductory article, the era of cheap energy is over, possibly forever. Expensive oil is the paramount result of last year's events in the Middle East, and the betting here is that high energy prices will endure. The dissenting, market-oriented view is that supplies of oil will increase, the cartel of oil-exporting countries will eventually collapse, and prices will come down again. But there is no free market in oil or other energy commodities, and little sign of the collective international will required to bring one about. Oil in the United States is unlikely ever to cost less than the present price of controlled domestic crude, about $5.25 a barrel (0.16 m^3), and will go higher if present subsidies in the form of favored tax treatment are removed. Higher prices for natural gas and coal, both now an incredible bargain compared to oil, also appear inevitable.

Higher prices will have dramatic effects, increasing the amount of domestic resources which it is economic to recover and decreasing the rate of growth of energy consumption. As a result, earlier estimates of energy needs, many of them self-servingly high, are probably out of date. The discrepancy can be gauged by comparing the National Petroleum Council's 1972 study, *U.S. Energy Outlook*, with the 1974 preliminary report of the Ford Foundation's Energy Policy Project, *Exploring Energy Choices*. The low energy growth projection of the earlier report, 3.4 percent per year, coincides with the high growth scenario of the more recent study.

Higher prices and the new energy consciousness, as C. A. Berg suggests elsewhere in this issue, may well trigger an industrial revolution in more efficient processes and energy-conserving equipment. Consumer pressure for smaller cars and emerging state and federal conservation policies will also help to limit demand for energy. Holding consumption to about 3 percent annual growth from now until 1985 appears technically feasible with modest conservation measures. Still more efficient use of energy and greater savings might be achieved with broad tax and regulatory incentives, especially after these measures were in effect for some years. (Most spokesmen for the energy industry disagree, predicting a more rapid growth in demand and asserting that slowing this growth will have economic repercussions.)

Even 3 percent per year could be a difficult target to meet. Oil and gas production are declining, and the future is beset with uncertainties. A new Middle East war, for example, could again shut off oil imports from that part of the world. Public concern about environmental damage could foreclose or at least delay drilling for oil and gas on the Atlantic and Pacific continental shelves and strip mining of coal in the western states. A serious reactor accident could swing opinion against nuclear power and lead to a ban against further construction. On the other hand, a wartime style crash program with effective government leadership and broad public support could solve the remaining technical problems and create sizable new synthetic fuel industries—oil and gas from coal, and shale oil—probably within 4 years, if necessary. The construction time for nuclear reactors could also be halved, and in-

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