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Energy Choices That Europe Faces: A European View of Energy*

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I. Demand and Supply of Primary Energy

Until the first industrial revolution (about 1870) solar power was the major source of primary energy. It was converted into wood, which in the context considered here can be labeled a form of secondary energy. The first industrial revolution then necessitated the switch to coal as a primary source of energy, which in the final analysis is also a form of solar power, of course. Up to the middle of the fifties domestic coal was available in sufficient quantities for a number of European countries (e.g. Germany, England, Belgium) to give them the status of energy self-reliance. After the Second World War low oil prices, the increasingly open market, and a certain ageing 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 fifties oil has conquered an ever increasing share of the expanding primary energy market in the booming economies of Western Europe and elsewhere.

Table 1 indicates this development and gives the relevant data for the case of the Federal Republic of

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Germany. The share of coal has fallen from roughly 70% in 1957 to a value as low as 23% in 1972, while the share of oil has risen from 11% to 56% accordingly. The absolute figures show a less dramatic decrease, which nevertheless is also severe. The share of oil in the Community of the Six is even higher. It is at 65% (1970), while the corresponding figure for the U.S. is at 43%. The important point is that in the case of the U.S. only about 1/3 of that oil is imported (or 13% of the total primary energy demand), while in the case of Europe practically all the oil is imported. This observation reveals a first and basic difference between the energy situation in the U.S. and Europe.

Table 2 gives the consumption in kW/capita in various European countries in comparison to that of the U.S. While the per capita consumption in Europe presently is at 40% of that of the U.S. it is expected to increase to values at 60% (1985). By and large this gives a factor of two between the U.S. and Western Europe and this establishes a second difference between the energy situation in the U.S. and Europe. It must be recognized, however, that the gross domestic product (GDP) per capita in Western Europe is much closer to that of the U.S. than indicated by the ratio of the per capita energy consumption. This, of course, follows a general trend to have such higher ratios of GDP/kW if the level of energy consumption is low. Here, I refrain from giving figures because this leads into the awkward problem of currency exchange rates. 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 U.S. and Germany.

II. The Limited Oil Supply from the Middle East and Possible Substitution by Coal

It has been estimated that the amount of crude oil in the Middle East is at $350 \cdot 10^9$ barrels or 2 Q (1 Q = 10^{18} BTU). If 430 million people (all of Western Europe plus Japan) at 10 kW/capita use oil to make up 2/3 of that amount this requires 0.09 Q/year. Therefore, the reserves of the Middle East will then last for about 23 years. If the U.S. participates in exploiting these reserves, the period is shorter accordingly. The actual period for these reserves to last will be somewhat different anyway but the figure of 23 years certainly is indicative. Dr. Khene, Secretary-General of the Organization of the Oil Exporting Countries (OPEC), made the observation [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. Dr. 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.

On the global average coal reserves are about fifteen times larger than oil reserves [2]. The natural substitute for oil therefore is coal. However, in so doing one must realize the large geographical differences of coal reserves that occur. The U.S. seems to have an unusually large portion of the total amount of coal, while this is not so in the case of Europe.

Table 3 tries to point to that direction. For reasons of comparison a consumption rate of 10 kW/capita has been assumed throughout that table. The 37 Q of the U.S. therefore last for more than 600 years if all 10 kW would be provided for by coal. Again, this figure and the others in the table shall only be indicative, the actual figures cannot be predicted so easily. Europe's main coal reserves are located in Germany and England. If they 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 would consume all the coal available to her it would be enough for 160 years. The figures become less drastic if coal reserves in depths greater than 1200 m are considered. They are given in Table 3 in parentheses. To contrast the figures for coal, Table 3 also gives the ones for domestic oil and gas. It is obvious that these domestic oil and gas resources are significant for a much shorter time period only (or for a much smaller portion of the supply of the primary energy, respectively).

It is therefore only natural that the U.S. prepare for the large scale use of coal including its related research and development [3]. The principal mode of such new uses of coal, however, is the burning of coal in whatever form: gaseous, liquid, or even solid.

Can nuclear energy reduce the degree of using coal? One has to realize that nuclear power was developed with an incentive to provide electricity that is competitive with (artificially) cheap fossil fuels (50¢/million BTU or less). At the same time the development of nuclear power was meant to act as a technological innovator. But it was not the goal to solve the early energy crisis. As a result, now amidst an energy crisis, nuclear power can at best take care of that portion of primary energy which goes into the production of electricity. While at present this is at 25% in Europe and 20% in the U.S. it is expected to increase steadily to values as high as 40% or more, because today one observes an annual rate of increase at 8% for electricity while the rate of increase for primary energy in general is at 4.5% only. In any event, one will try to ease the switch from oil to coal by shifting the production of electricity to nuclear power to the largest extent possible.

Accordingly, the Government of the Federal Republic of Germany recently announced an energy plan for the years up to 1985. There nuclear energy is expected to assume 15% of the primary energy demand, which relates to 45 GWe. Similar percentage figures have been given for the U.S. But contrary to the U.S. it will be difficult to raise the coal production in Europe: Most of the miners are gone. Table 4 is meant to illustrate that development. The German coal production is now down from 141 million tons (metric) in 1962 to 102 million tons in 1972. The productivity per miner and shift has risen from about 2.4 tons to 4 tons, and therefore the number of employees in the coal industry is down from 434 000 to as low a figure as 221 000. The figure for employees actually engaged in mining is still smaller. It has been estimated that it will be virtually unfeasible to raise the coal production to more than the original 140 million tons/yr. If, by contrast, in 1985 coal production should continue and, in addition to it, shall substitute oil as a primary energy source, this would mean a coal production of 380 million tons in the case of the Federal Republic of Germany alone. 330 out of these 380 million tons would be for the substitution of oil by synthetic fuels, while only 50 million tons would be for genuine coal consumption. If the relatively coal-rich Germany would have to deliver coal to other European countries, the coal production required would be higher accordingly. This would soon make it necessary to go to depths greater than 1200 m and this amplifies, as mentioned above, the coal problem, or more specifically, the labor problem related to the coal problem. It can hardly be overestimated. 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 U.S., and this is another very significant difference between the energy situation in the U.S. and Europe. Undoubtedly there is a strong incentive to look into new coal mining technologies; it remains to be seen to what extent this can be successful.

III. The Three Phases of the Energy Problem

It has been indicated that the global resources of fossil fuel are at 200 Q [2]. With 10^{10} people and 10 kW/capita this gives a period of only 66 years for these resources to last. Naturally, this oversimplifies; reality is more complex and actual figures would be different but it is possible to draw one simple conclusion from this little algebra: In a not too distant future we have to live with an energy supply that comes from non-fossil fuel resources.

There are four options for such non-fossil energy supply [4]:

1) nuclear fission in the fast breeder and other reactors,
2) nuclear fusion,
3) solar power, and
4) 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 technically feasible already now. 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 still before it will be possible to make assessments.

Keeping in mind therefore that eventually there could be more than one option for the long range supply it is now nuclear fission which shall be examined further since it is the only option already viable today. It has been said earlier that nuclear power was developed for the competitive production of electricity only. If electricity has a share of not more than 40-50%, how can nuclear fission be the source of all the primary energy demand? The answer is: by reactors which provide process heat at high temperatures. The incentive to developing such reactors now comes out to be larger than the incentive to develop and operate reactors for the production of electricity. Fortunately, in the U.S. there is the High Temperature Gas Cooled Reactor (HTGR), which has been pushed by the Oak Ridge National Laboratory and 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. The most convincing scheme in the long run for the use of nuclear process heat is the splitting of the water molecule and by that the truly large scale use of hydrogen as a secondary fuel. Hydrogen would then complement electricity as another secondary fuel. Recently much attention has been paid to this long range option and so I refrain from elaborating further on this point [6]. At Gulf General Atomic [7] and at the Kernforschungszentrum Karlsruhe, Germany, the idea came up to employ the breeding gain of fast breeder reactors for providing the necessary U^{233} fuel for the high temperature gas cooled reactors. In such a scheme, where energy consumption has leveled off and no longer increases significantly, all of the secondary energy in the form of electricity would be produced by fast breeders, while all of the secondary energy in the form of hydrogen would be produced by high temperature gas cooled reactors 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 at 3:2, which generally fits with market requirements. Figure 3 illustrates such an asymptotic integrated reactor scheme. The only input there is U^{238} and Th^{232}, and these are abundant isotopes. In a paper by W. Häfele and W. Schikorr [8], the transition periods from today into such an asymptotic scheme also have, in a first round, been evaluated. A model society was considered which today has 250 million people, which grows to 350 million people within 40 years and which then remains constant. It was further assumed that the share of primary energy devoted to the production of electricity is now 25% and will grow up to 50%. Nuclear reactors are installed as Light Water Reactors (LWR) at a rate of 18 GWe/year at first. After about 18 years the yearly plutonium output of these LWR's is large enough to provide the plutonium first core inventories of fast breeders (FBR) built at the same rate of 18 GWe/year. A switch from LWR's to FBR's after these 18 years has been assumed therefore. At the same time the installation of HTGR for the production of hydrogen is possible. 18 GWe correspond to 45 GWth, and due to the coupling of U^{233} (production in FBR's and consumptions in HTGR) a rate of introduction of HTGR's of 45 GWth/year has been assumed accordingly. The installation of FBR's and HTGR's continues until all of the primary energy demand is met and all LWR's are replaced by FBR's. It then becomes obvious that until that time fossil fuel and cheap uranium for feeding the LWR's with U^{235} are required during the transition period. Note: In such a scheme FBR's act as a final waste box for all the plutonium that is produced by the limited generation of LWR's; at the same time FBR's produce the necessary electricity and the necessary U^{233} that allows for the production of hydrogen. It is a radically different use of the virtues of fast breeders; no doubling of any kind is taking place. A few of the results obtained so far are given in Table 5. The 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 naturally would be smaller. 3 Q fossil fuel are required to master the transition. The model society considered here is in the vicinity of European conditions. The required 3 Q fortunately somehow fit with the genuine European coal reserves as indicated in Table 3. The major conclusion within the constraints of the model employed here 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 U.S. too is in the vicinity of this model society. But her coal reserves are larger by an order of magnitude if all U.S. coal is to be burned within the U.S. In these conditions the relevant transition period accordingly is much longer. It should be discussed, however, whether all coal of the U.S. should go into domestic consumption. Further, Table 5 points to the relatively large consumption of cheap uranium during the transition period. Therefore the supply of cheap uranium could earlier become a concern than the supply of coal. More work is going on to evaluate this scheme in greater detail [9].

Here it must be emphasized that the coupling of FBR and HTGR not necessarily is meant to be the only scheme of interest. The potential of the heavy water reactor, the possibility to produce hydrogen by electrolysis, the option to fuel HTGR's with Pu and many others have to be taken into account in such an approach, too. The consideration extended here is primarily meant to bring in a new general possibility.

Against this background of an asymptotic phase for the provision of energy on a non-fossil basis it is obvious that the new uses of coal are the characteristics of a transition period. Such a transition period in itself requires major technological preparations and change. Until such technological changes can become effective again some time will elapse, and this then characterizes the near term phase of the energy problem. Table 6 identifies these three phases of the energy problem.

Timing and the evaluation of it, for instance by systems analysis, therefore come out to be the principal points of attention in the energy problem. One aspect of that is to make the various research and development activities 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 pointing to 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.

IV. Secondary Energy

As observed earlier 75% of the primary energy in Europe today is devoted to non-electrical purposes. About 55% goes into stationary applications while 20% or so goes into transportation. In Germany it was R. Schulten who conceived and promoted the idea of the pebble bed reactor [10]. This is a reactor where a random package of balls of about 5 cm diameter make up the core. The fuel elements are balls and not rods. With an appropriate fuel management scheme (the OTTO scheme (Once Through Then Out, [11]) this pebble bed reactor is particularly well suited for high temperatures. On February 27, 1974, the Jülich AVR experimental reactor for the first time reached an outlet temperature of 950° C, which allows for chemical process heat in many applications. R. Schulten and 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, albeit promising, scheme for such a transformation into chemical binding energy. A more near term application for instance would be the application of nuclear process heat to the well known chemical reaction

$$CH_4 + H_2O + 49\,\frac{\text{k cal}}{\text{mol}} \rightleftarrows 3\,H_2 + CO \quad .$$

Figure 4 indicates the procedure for such an application. 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 they can be transported over any distance. On the consumer side they are led to react and give away their chemical binding energy. Methane is transported back to the power station. The chemical reactor for the production of hydrogen and carbon monoxide is called EVA (Einzelspaltrohrversuchsanlage), 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) Beside losses no material other than nuclear fuel is consumed. No fossil fuel except for the one time inventory of the pipes is required.
4) It employs technology that is basically available already now.

At the Kernforschungsanlage Jülich the demonstration of that scheme over a distance of a few miles and in the MW 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. Note: electricity also leaves the environment untouched for this reason.

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 better suited 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 as one of 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 ADAM and EVA scheme are estimated to be at \$2/million BTU for the consumer. Let us consider this as being indicative to the relevant range of energy prices. It parallels an oil price of \$12/barrel (at the consumer) and is now somehow in line with the present oil market. Against this background it is interesting to look at the already existing pipeline system for gases in Europe.

Figure 5 gives a map of the existing European pipelines for gases. It is already a fairly tight system. On the basis of $400 000 /km for pipelines larger than 20" and $240 000 /km for pipelines smaller than 20" the investment costs for the existing pipeline system have been estimated to be somewhere at $15 billion. To establish a more extended modern pipeline system may cost something like $200 billion. For putting this figure into perspective it is worthwhile to consider the present worth of the energy that is put through that modern pipeline system. At 5 kW/capita of heat and 327 million people with $2 /million BTU one arrives at the linear value of $\$10^{11}$ /year and with a discount rate of 15% at a present worth of about $700 billion. In view of the global energy challenge and a present worth of $700 billion an investment of $200 billion, large as it is, appears to be acceptable. This is especially so because it spreads over at least 10 years. At 327 million people this amounts to $60 annually per person over a period of 10 years. True, this is not the only expenditure. The central power plants and other devices must also be built. Nevertheless, this figure indicates the order of magnitude that is at stake. I intentionally refrain from elaborating on the question as to what extent a mere market mechanism shall bring this change about and to what extent an emergency type venture must be envisaged.

If the above consideration deals with process heat for stationary applications--what about transport?

I feel that the answer is to make use of coal for synthesizing hydrocarbons. Methanol seems to be a promising avenue [15]. Its heat content is 170.9 $\frac{\text{k cal}}{\text{mol}}$, that of carbon is 94 $\frac{\text{k cal}}{\text{mol}}$. The ratio between these two is 1.8, or in other words, the worth of carbon can be multiplied by the factor of 1.8 if the difference in chemical binding energy is provided for by a non-fossil fuel source. I refer, of course, to nuclear process heat. If 20% of the primary energy demand is for transportation this means in effect that only 20%/1.8 = 11% have to be taken over by carbon as a source of primary energy. Other chemicals have to be considered, too, and in particular the production of methane. In that case the coal reserves are multiplied by a factor as large as 2.2 and the lower weight of methane could make it a fuel feasible for aviation purposes. One must also continue to keep hydrogen in mind. R. Schulten and others have made the observation that only such a reduced percentage of coal used for transportation purposes shall be obtained through the burning of coal. This would be indeed in sharp contrast to the situation in the U.S. 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, the 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 and the technology for handling process heat as chemical binding energy as well as the technology of pipelines and chemical engineering. If properly put together it could be a more or less final answer to the energy problem already during the transition period. This solution to a large extent could reestablish Europe's self-reliance and could alleviate the oil situation.

V. Primary Energy Parks

A large and modern pipeline system tends to deemphasize the question of siting of large power plants which provide chemical process heat for the use in chemical reactors such as EVA. It was stated above that large central power plants could assume the function of natural gas fields. This induces the idea also to look at electricity and to see whether there is the possibility of centralizing large power plants. Such a step would require an extension of the electrical grid. The existing 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 as low as 100 km. The existing high voltage lines serve to reduce standbys and the handling of peak loads. At 380 kV they can transmit about 5 GW over distances of 500 km. An extension of technology into the domain of 10-50 GW therefore is required. Ultra high voltage direct current lines or super-conductive cables [16] probably can 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 accordingly.

Such a modern infrastructure for the handling of secondary energy, gases and electricity, then indeed tends to deemphasize the question of siting large power plants. This could be important in the long run. Let us consider for instance the cooling water requirements for the production (conversion) of primary energy. If electricity assumes 50% of the primary energy production and has a thermal efficiency of 0.4 while the other 50% of the primary energy production are for the production of chemical process heat at a thermal efficiency of 0.6, then out of 10 kW/capita as much as 5 kW/capita are waste heat at the sites where the secondary energies are to be produced. With $3.27 \cdot 10^8$ Europeans this leads to a total of $1.6 \cdot 10^{12}$ W of waste heat at the site of the power plants. Wet cooling towers allow dissipation of $3 \cdot 10^9$ W per m^3/sec of water. $1.6 \cdot 10^{12}$ W therefore require $1.6 \cdot 10^{10}$ m^3/year if that waste heat is to be dissipated in wet cooling towers. The rainfall in <u>central</u> Europe is at 0.8 m/year thus giving 0.8 $m^3/\text{year} \cdot m^2$. Therefore $2 \cdot 10^{10}$ m^2 are required if <u>all</u> of the related rainfall would be given to wet cooling towers. If more realistically only 10% of all the rainfall, and that means

20% of all runoffs in rivers, creeks, etc., would be given to wet cooling towers then an area of 500 km x 500 km would be required within which such collection of water had to take place. This little algebra, crude as it is, points to the severe 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 steadily more so 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 strongly feel that such embedding will be the principal driving force 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 dramatic 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 proposed by A.M. Weinberg and R.P. Hammond [19]. Many of the concerns about nuclear power could be eased in this way. If in the long run solar power comes out to be a feasible solution it will, in any event, require large areas for the harvesting of solar energy. I feel that not more than 20 W/m^2 can be expected. If all of the primary energy demand of Europe shall be provided by solar power this would then require an area of 400 km x 400 km. Such a large area would best be found in the open sea. This of course immediately leads to problems of the law of the seas but it is consistent with the idea to have 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 feel that nuclear fission and in particular the combination of FBR and HTGR will continue to play a dominant role. But if other options come out to be better let us employ them in primary energy parks. The continents would remain unaffected. Remarkably enough, already today such primary energy parks are under development in Europe. In Figure 5 the pipelines are shown which connect the continent with floating platforms above the new (albeit in the long run limited) gas fields of the North Sea. This suggests a later transformation of such platforms into energy parks.

VI. Concluding Remarks

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 largely there already. 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, as at least in principle 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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Table 1. Annual demand for primary energy for the Federal Republic of Germany

	1957	1967	1972
	% of total	% of total	% of total
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
$\hat{=} 10^6$ mtce/yr.	198	271	362
$\hat{=}$Q/yr.	0.0054	0.0074	0.0099

$1Q \equiv 10^{18}$ BTU $\hat{=}$ 2,93 $\cdot 10^{14}$ kWh $\hat{=}$ 2.52 $\cdot 10^{17}$ k cal

$\hat{=}$ 3.6625 $\cdot 10^{10}$ metric to coal eq. (mtce)

Source: Das Energieprogramm der Bundesregierung. Report of the Bundesministerium für Wirtschaft, Federal Republic of Germany, Bonn, 1973.

Table 2. Consumption of energy per capita in Europe and the U.S. (in kW/cap)

	1970	1975	1980	1985
Belgium	5.6	7.3	9.0	10.7
France	3.9	4.8	6.1	7.7
F.R. 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
U.S.A.	10.9	12.3	13.7	15.2
$\frac{\text{European Communities}}{\text{U.S.A}}$	0.404	0.472	0.526	0.586

Source: Prospects of Primary Energy Demand in the Community (1975-1980-1985), Commission for the European Communities (72.10.04).

(The dates of U.K. fit into the here extended pattern of energy consumption.)

Table 3. Coal, lignite, and oil reserves in Western Europe and U.S., and periods for these reserves to last

		F.R. Germany	Western Europe	U.S.
Coal and Lignite Reserves	(Q)	2.92 (+4.37) 1)	3.50 (+4.37) 1)	36.69
Oil and Nat. Gas Reserves	(Q)	0.017	0.214	0.469 2)
Annual Consumption for 10kW/cap	(Q/yr)	0.018	0.098	0.061
Period of time, if				
Coal	(yr)	160 (+238)	36 (+44)	602
Oil and Natural Gas	(yr)	0.9	2.2	7.7
is used exclusively 3)				

$1Q \equiv 10^{18}$ BTU $\hat{=}$ $2{,}93.10^{14}$ kWh $\hat{=}$ $2.52\cdot 10^{17}$ k cal $\hat{=}$ $3.6625\cdot 10^{10}$ metric to coal eq. (mtce)

1) Reserves in depths below 1200m, the use of which today is not feasible economically and sociologically.

2) Tar sands and shale oil not included.

3) No population growth assumed.

Source: Figures derived from data of the Statistical Yearbook of the United Nations, New York, 1973.

Table 4. Coal production in the Federal Republic of Germany

Year	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 (in thousand)	434	399	334	264	250	221
Coal produced per miner and shift (metric tons)	2.37	2.61	2.93	3.53	3.76	4.02

Source: Das Energieprogramm der Bundesregierung. Report of the Bundesministerium für Wirtschaft. Federal Republic of Germany, Bonn, 1973.

Table 5. Transition into an all nuclear energy supply for a model society

Reactor construction capacity	18 GWe / year (LWR or FBR for electricity generation)
and in addition after 18 years	45 GWth / year (HTGR for process heat generation)
Length of transition period, i.e. time until total reliance on nuclear energy is achieved	≈60 years
Total energy consumption during transition period	≈ 6 Q
Amount of fossil fuel required during transition period	≈ 3 Q
Amount of cheap natural uranium required during transition period	≈ 3.10^6 tons

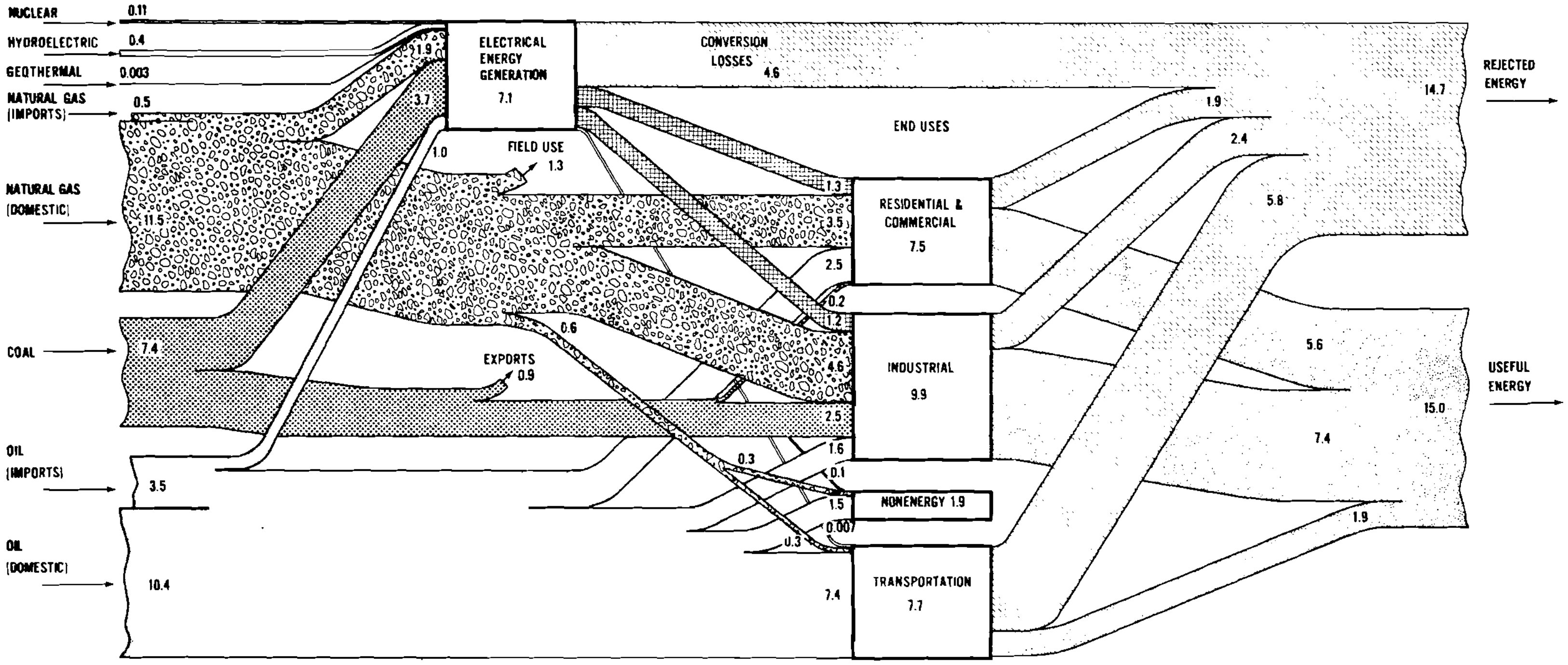
Assumption: Model society with 250.10^6 people at t = 0 and 360.10^6 people at t = 40 years and 10 kW /cap. in the asymptotic state (see text).

$1Q \equiv 10^{18}$ BTU $\hat{=} 2.93 \cdot 10^{14}$ KWh $\hat{=} 2.52 \cdot 10^{17}$ k cal $\hat{=} 3.6625 \cdot 10^{10}$ metric to coal eq. (mtce).

Table 6. The three phases of the energy problem

	Characteristics				
Asymptotic Phase	Based on either nuclear fission, fusion, solar, geothermal power or a combination thereof.	from	2050 in Europe 2200 in the U.S. (??)	to	for ever?
Transition Phase	Based on the substitution of oil by coal and on nuclear energy for the production of electricity.	from	1985	to	2050 in Europe 2200 in the U.S.(??)
Near Term Phase	Characterized by the administration of fuel shortages and the preparations for the transition phase.	from	1973	to	1990

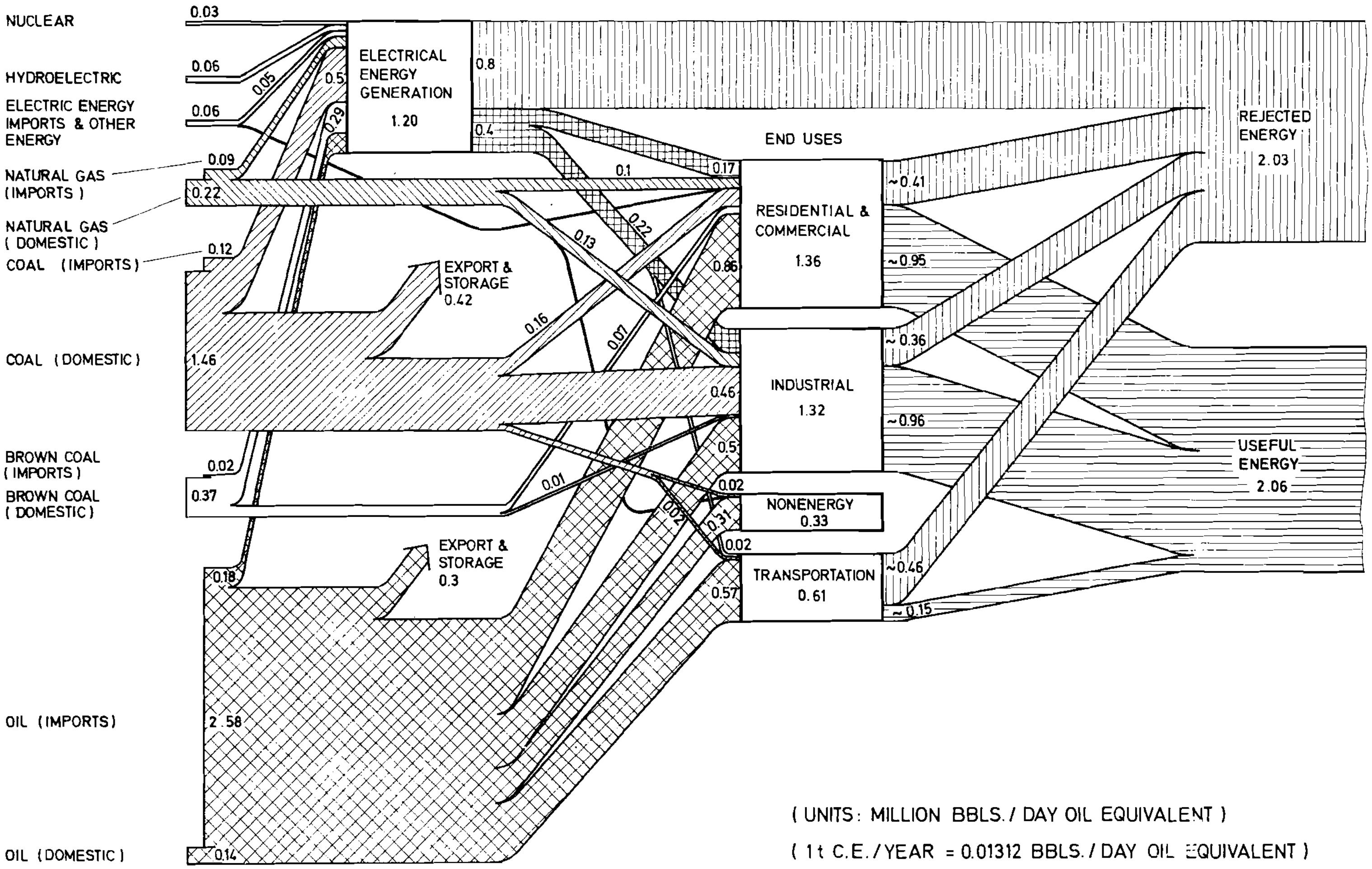
TOTAL ENERGY FLOW PATTERN U.S. (1970)



(UNITS: MILLION BBLS./DAY OIL EQUIVALENT)

Figure 1

TOTAL ENERGY FLOW PATTERN FRG (1971)



(UNITS: MILLION BBLS./DAY OIL EQUIVALENT)

(1 t C.E./YEAR = 0.01312 BBLS./DAY OIL EQUIVALENT)

Figure 2

ASYMPTOTIC INTEGRATED POWER REACTOR SYSTEM

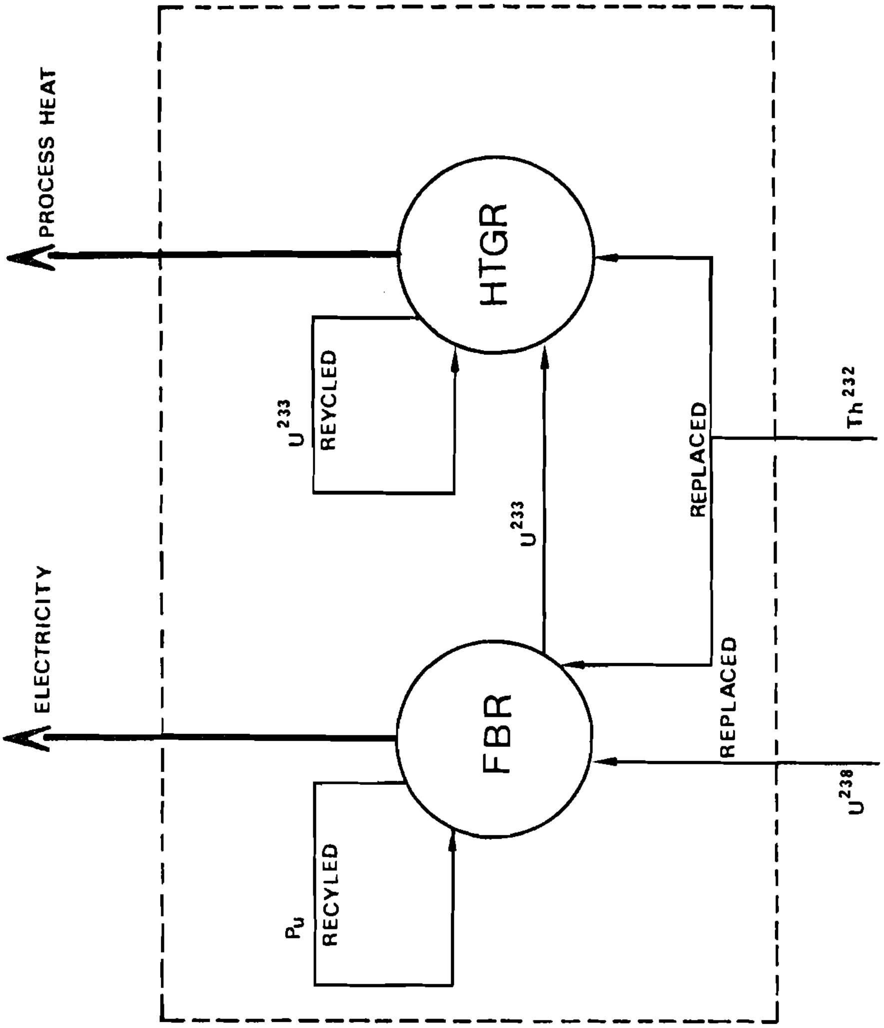


Figure 3

ENERGY TRANSMISSION SYSTEM EVA + ADAM

$$3H_2 + CO \rightleftarrows CH_4 + H_2O$$

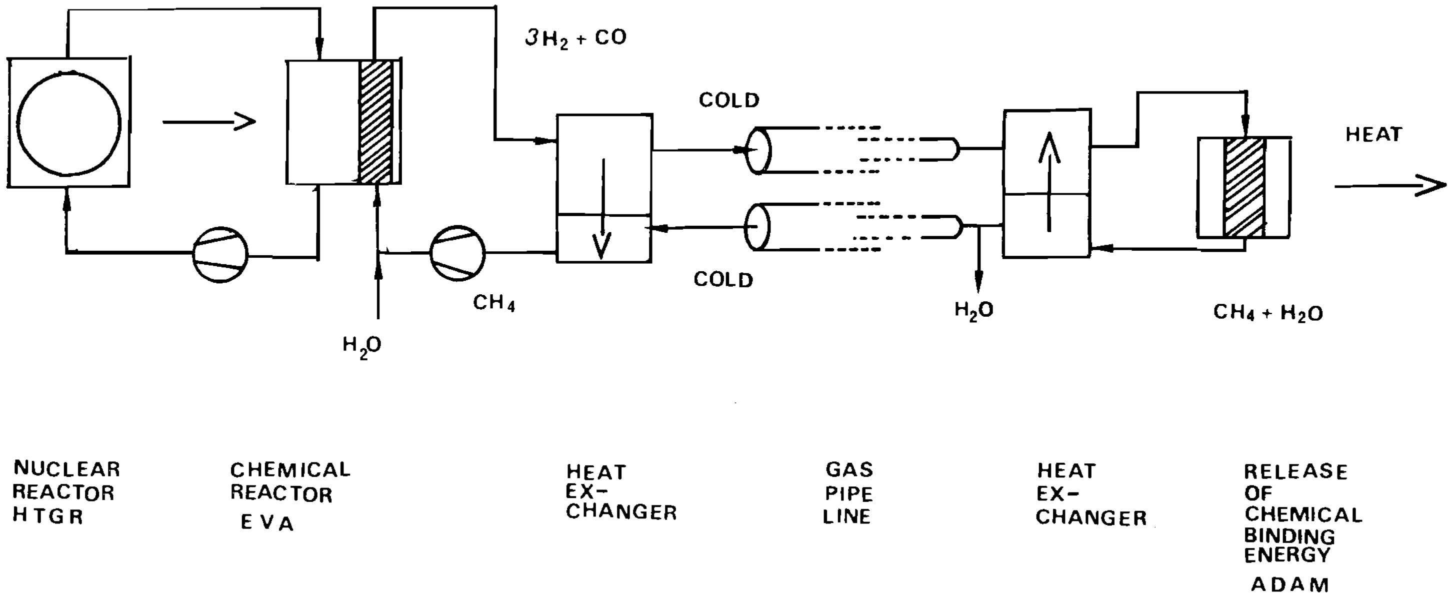
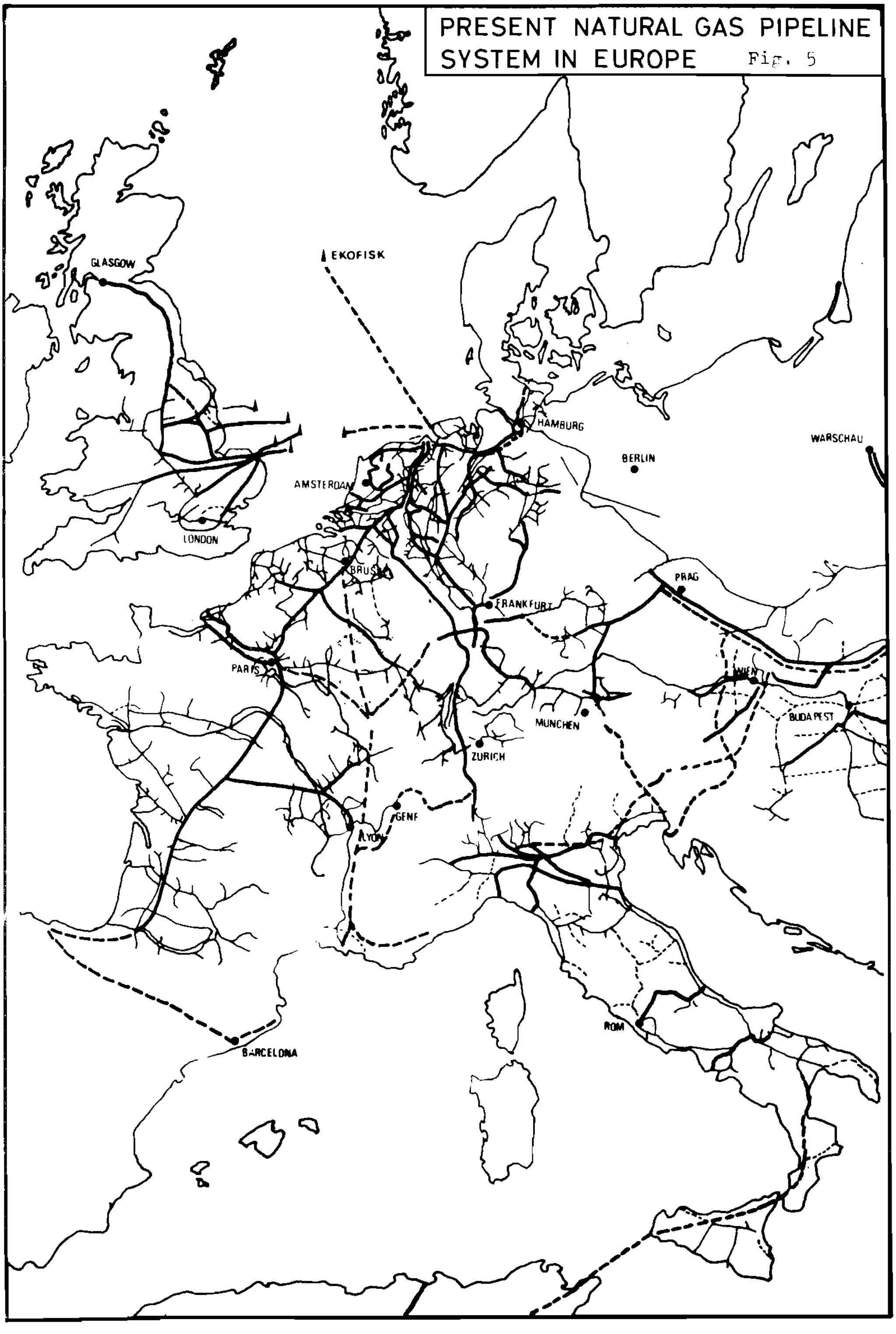


Figure 4



PRESENT NATURAL GAS PIPELINE SYSTEM IN EUROPE Fig. 5

Fig. 1 Total Energy Flow Pattern U.S. 1970
(Source : Joint Committee on Atomic Energy,
Certain Background Information for Consideration
When Evaluating the "National Energy Dilemma",
U.S. Government Printing Office Washington, (1973)

Fig. 2 Total Energy Flow Pattern FRG (1971)
(Source : Energieflußdiagramm BRD 1971,
Bergbau-Forschung GmbH, (1973)

Fig. 3 Asymptotic Integrated Power Reactor System
(Source : Ref. [8])

Fig. 4 Energy Transmission System EVA + ADAM
(Source : Ref. [13])

Fig. 5 Present Natural Gas Pipeline System in Europe
(Source : Niedersächisches Landesamt für
Bodenforschung, Hannover, Jahrbuch für Bergbau,
Energie, Mineralöl und Chemie, Verlag Glückauf GmbH,
Essen (1973)

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