Biomass, for the production of alcohol as well as charcoal, will have an enormous role in the future. The historical association of the use of wood with underdevelopment will have to be counteracted by pilot projects and demonstrations of the utility of biomass. The reorientation of the steel industry toward the use of charcoal instead of mineral coal has been done to some extent and should be encouraged, together with a coordinated program of reforestation.

Nuclear energy will have only a secondary role in energy production in Brazil; efforts to promote a widespread use of this form of fossil energy cannot be justified. High-grade uranium resources are small in Brazil, and serious risks would be associated with a new dependence on imports of nuclear fuel.

Although oil shale is abundant, the extraction of the oil poses serious technical and environmental problems, and this resource should probably be used only in the chemical and pharmaceutical industries. Recovery in situ might eventually prove to be an attractive technology.

In the overall picture, Brazil seems to be capable of finding within its own frontiers most of the energy needed to sustain its population.

New patterns of energy consumption will have to be adopted in Brazil. The construction of completely enclosed buildings—requiring constant air conditioning—in Brasilia and other cities in the temperate regions of the country indicated a total disregard for efficient energy use. The Portuguese colonizers some 200 years ago constructed simple but functional buildings and with some effort it should be possible for Brazilians today to design a new type of "tropical civilization" that is appropriate to the environment.

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Energy Options and Strategies for Western Europe

Wolf Häfele and Wolfgang Sassin

The present world energy situation is characterized by total consumption at an average rate of about 7.5 terawatts (1 TW = 10^{12} watts) of thermal energy; this is roughly equivalent to 8 billion tons of coal equivalent per year. As much as 5.5 of this 7.5 TW is supplied today by oil and gas, and this high proportion has built up through the last 30 years. Oil systems as we know them today have a low capital cost investment [~ \$50 per kilowatt thermal (kWt)]; they are clean, easy to handle, and can easily adjust to market and end-user requirements. Not exactly but essentially the same is true for natural gas. It is therefore quite natural that the energy situation of Western Europe is mostly reflected by the supply of oil and gas. For the member nations of the Organisation for Economic Co-operation and Development (OECD), the *World Energy Outlook* (*1*) expects a total energy requirement in 1980 of 1400 million tons of oil equivalent, which is practically 2 TW. Of this, about 0.9 TW is expected to be supplied by oil, which amounts to roughly 12 million barrels per day (MBD). Reasonable estimates of the expected oil imports of the United States and Japan are 10 and 7 MBD, respectively, giving a total for these countries and Western Europe of about 30 MBD for 1980. Under present circumstances oil production by OPEC (the Organization of the Petroleum Exporting Countries) might be between 33 and 45 MBD. A recent study by the Workshop on Alternative Energy Strategies (WAES) (*2*) indicates that a ceiling of 45 MBD for OPEC production might lead to a gap between supply and inherent demand by 1990, and a ceiling of 33 MBD might lead to such a gap as early as 1982.

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Competition for Buying Energy

If and when world oil demand outstrips supply, who gets the OPEC oil? The answer is, those who can pay. In the WAES study oil prices up to \$24 a barrel are considered; three questions follow from it.

1) Which countries will maintain a strong enough balance of payments to pay for the high-cost oil, and what will be the effect of such high oil prices on the world trade pattern?

2) How much oil will be added to world reserves at a price of \$24 a barrel, and what are the lead times for producing from these additional resources?

3) What is the domestic resource base

of each of the nations competing for oil imports and, more generally, for energy imports?

The first question is essentially one for national and international economists; we will deal with it only briefly here. The order of magnitude of the problem is indicated by the fact that in 1970, when the overall energy price was roughly $3 a barrel, an average of 3 percent of the gross domestic product (GDP) of all countries was given to the energy sector, while the total exchange between world trade partners was about 9 percent of the GDP. Countries that had to import all of the energy they required therefore had to devote one-third of their trade to pay for it. One might naively conclude that at $24 a barrel, 24 percent of the GDP would have to go into exports in order to buy the imported energy. The picture is more complex, but such energy prices would certainly open a new era of competition in which only a few countries, if any, could win.

The second question is quite important. Oil has always been explored in terms of ratios of reserves to production such that there are enough proved reserves for, say, 10 or 15 years under current circumstances. By contrast, coal has been explored mostly on geological grounds. Present estimates for oil reserves are 90 billion tons, but geological evidence suggests that the figure should be much higher. Experts at the 1977 World Energy Conference in Istanbul estimated recoverable petroleum resources worldwide to be about 260 billion tons, assuming that the present recovery rate of 25 percent will be raised to 40 percent toward the end of the century (*3*). This does not include deep offshore and polar resources, which are still classified as unconventional petroleum; including these the estimate is 300 billion tons. In fact, some estimates by individual experts are higher, up to 600 billion tons. Thus, there may be significantly more oil in the ground, but its recovery is very uncertain. To actually produce such quantities would require industrial activities that are economically and institutionally infeasible today. But this sheds light on the dimension of the problem. Whether Western Europe would be able to participate in such activities is open to question. In any event, they would take several decades. The real question is whether there is enough time.

The third question raised by WAES has to do mostly with coal and uranium. About 85 percent of all coal reserves and resources are in the United States, the Soviet Union, and China. The possibility of intensified use of coal is receiving more attention (*4–6*), particularly in the United States. However, the environmental and social costs of such intensified coal production would be considerable. It is not surprising that there have been no indications so far that any of the above countries would consider or would be capable of assuming a role in coal production like that of OPEC in oil production. Indeed, most of the OPEC countries have little choice but to trade in their natural resources for the industrial goods they need for consumption and development. This is not the case for the United States and the Soviet Union, and probably not for China, which in any event is a special case. What is left for Western Europe therefore is its own coal reserves and resources. West Germany and Britain are the coal countries. The proved reserves of both countries taken together are 70 billion tons of coal equivalent, or roughly 65 TW-years. In view of the total yearly energy consumption of 2 TW today and perhaps up to 4 TW during the next three or four decades, 65 TW-years is an uncomfortably low figure. However, the established resources in the ground are higher by up to a factor of 6. This coal is very deeply located, as deep as 5000 meters. Coal beds extend from the Ruhr area down to the bottom of the North Sea and to the coal mines of Britain. As in the case of additional amounts of oil, actual production of this coal would necessitate industrial activities that are economically and institutionally infeasible today.

While coal reserves and resources are somewhat known, the same is not true for uranium. The amount of available uranium as a function of price is the subject of an ongoing debate. For a quick orientation, it might be stated that roughly 5 million tons of uranium should be available at prices up to $60 a kilogram and perhaps 10 to 20 million tons at prices up to $200 a kilogram. The salient point for Western Europe is that no significant amounts of *cheap* uranium, say up to $60 a kilogram, seem to be available. The amount of energy available from light water reactors (LWR's) using 5 million tons of uranium is roughly 35 TWe-years (TWe, terawatt electric). It should be kept in mind, however, that about 6 TWe-years is already committed for existing and firmly planned power plants. Getting energy from LWR's would imply, as in the case of coal and oil, a competition for uranium imports.

Summary. Western Europe, now largely dependent on oil imports, has to prepare for strong competition for oil and energy imports in general before the year 2000. The more unlikely it is for Western Europe to secure from outside rich supplies of coal or uranium at readily acceptable economic and political conditions, the more serious this competition becomes. Even exceptionally low projections of economic growth and optimistic assumptions about energy conservation urgently call for vigorous and simultaneous development of indigenous coal and nuclear sources, including the breeder. Long-term contracts for the possession and deployment of foreign oil, gas, and coal deposits are mandatory and should be negotiated in view of the possible aggravation of north-south confrontation.

Prospects for Western Europe

What, then, is an appropriate strategy for Western Europe? To elaborate on this question we take as an example the Federal Republic of Germany. Its present yearly consumption of energy is roughly 380 million tons of coal equivalent (MTCE). In 1975 a demand of 700 MTCE was projected for the year 2000. Because of slower economic growth, a declining population, and more rigorous energy conservation measures, experts now project 600 MTCE for the year 2000 (*6a*). Where will 600 MTCE come from? A recent study by German coal experts in collaboration with the International Institute for Applied Systems Analysis (IIASA) (*5*) suggests that 200 MTCE each will come from hard coal and nuclear power, and that the remaining 200 MTCE must continue to come from oil imports. Let us review each of these amounts.

In terms of both supply and consumption, 200 MTCE from hard coal is a high figure. Use of coal in West Germany has been narrowed down to electricity and steel production. In 1980 there might be 35 MTCE for the former and 41 MTCE for the latter, totaling not more than 76 MTCE. Present efforts are being directed to maintaining this level, and it would seem difficult to increase it in view of the realities of the next 10 years. Environmental standards are becoming more stringent, and it is not clear whether plans to restrict sulfur dioxide emissions to 1.5 kg per megawatt-hour (MWh) will not further suppress the use of coal. Public opposition to coal has already led to construction delays in some cases (for instance, at Voerde). In order to concentrate on the physical aspects of the problem, for the rest of this article we will idealistically assume that issues related to public acceptance of coal and nuclear power will be resolved.

Increased use of coal will in any event require a fresh look at this problem and new technological solutions. Fluidized bed combustion for electricity generation offers great improvements with respect to the environment; capital costs of 700 deutsche marks per kilowatt electric (DM/kWe) could lead to applications in the load range of 4000 hours per year and 0.06 to 0.08 DM/kWh beginning in 1985. Unfortunately, the ratio between the deutsche mark and the dollar is constantly evolving, and it is not clear how these costs translate into dollars and mills. For the purposes of this article we assume an exchange rate of 2.5 DM per dollar, so the equivalent values are $280/kWe and 24 to 32 mills/kWh. Process heat for industry at 7000 hours per year could substitute for heavy fuel oil at $85/kWt beginning in 1985, and synthetic natural gas at 7500 hours per year (for example, by the LURGI gasification process) could be used at $350 per 1000 m³ beginning in perhaps 1990. Optimistically, by the year 2000 all these new technologies could lead to a consumption of roughly 120 MTCE. Together with the conventional uses of coal, this could make up the envisaged 200 MTCE. But it will not be easy and will require persistent pursuance of an energy strategy.

Let us also look at the supply side. It is not likely that domestic production can exceed a level of 120 to 140 MTCE as long as the industrial undertakings considered above remain infeasible. There is now increasing awareness within German coal circles that the country may need to import 60 to 80 MTCE annually by the year 2000. One should bear in mind that the present scale of world coal trade is only about 200 MTCE. Also, West Germany and Britain, where similar trends were found, are traditionally looked on as coal exporters rather than importers. The fact that the rest of the Western European countries have an even greater need for imports shows the severity of the situation.

What about the idea of West Germany having a nuclear capacity of 200 MTCE by the year 2000? This corresponds roughly to 130 gigawatts electric (GWe). The country's present nuclear (LWR) capacity is 7.4 GWe, and plants that will produce an additional 14.8 GWe are licensed and under construction. For 1985 it is not realistic to expect a nuclear capacity of more than 25 GWe because of public opposition and other uncertainties. Requiring 105 GWe in 15 years means a rate of 7 GWe per year. This seems physically possible, but our earlier idealistic assumptions about public acceptance should be kept in mind.

For Western Europe as a whole the World Energy Conference estimated two types of energy demand, unconstrained and constrained (that is, without and with energy conservation) (*7*). The projected unconstrained demand for the year 2000 is close to 3.5 TW, while the constrained demand is 3 TW. The partitioning of supply between coal, nuclear, and oil for all of Western Europe differs from that for West Germany. It is given as 21 percent for coal, 17 percent for nuclear, 50 percent for oil and gas, and 12 percent for renewable resources. In absolute amounts this would mean for the case of constrained energy demand: 630 MTCE for coal, 510 MTCE for nuclear, 1500 MTCE for oil and gas (or 21 MBD), and 360 MTCE for renewable resources. The overall misfit is fairly obvious: domestic coal production cannot be developed fast enough in Western Europe, nuclear is lagging behind, and the projected oil and gas imports are more than can be easily borne and perhaps more than will be available, even with an assumed 15 percent conservation potential and an assumed 12 percent share for renewable resources.

Two Inexhaustible Energy Sources

In the very long run there are two essentially inexhaustible energy sources: nuclear breeders and solar power. The case of nuclear breeders has been discussed over and over again (*8*) with regard to the mechanism of fuel supply and nuclear engineering, and we will not repeat it all in this article. The point that must be made here instead concerns the timing of nuclear breeders. For Western Europe they cannot come early enough. Similar to its dependence on oil imports is its situation with respect to uranium, which is worsening the more LWR's are used. The impending renegotiation of the United States, Canada, and the European community for the supply of enriched and natural uranium speaks for itself. Beyond the question of sufficient uranium reserves, the political security of the supply is at stake—which also implies that the related technology must be indigenously available. It is therefore not surprising that all major Western European industrial nations continue to pursue their fast breeder programs vigorously—France with Italy, West Germany with Belgium, the Netherlands, and Britain. It should also be noted that very close cooperation between the continental fast breeder programs was initiated recently and is now materializing (*9*).

The other inexhaustible source is solar power. It is important to make a distinction between production of solar power for local applications such as water and space heating and bulk solar power production for base load purposes. This problem has been studied in detail—for instance, at IIASA for the case of Austria (*10*). It is certainly not the yearly average solar radiation that limits the applications of solar power in Western Europe. As much as 3 kWh/m²-day can be expected for this yearly mean, while in equatorial regions not more than 5 to 6 kWh/m²-day is available. The big difference is the summer-winter fluctuation, which is roughly 8:1 for Western Europe and 2:1 for equatorial regions. The salient point therefore is energy storage, and local applications of solar power crucially depend on the intended level of storage. With storage covering a period of 1 week or so total solar energy system costs might be on the order of $20/MBTU, compared to ordinary heating costs today of about $7/MBTU—a difference of a factor of 3 (some people say it would be greater). This level of solar heating ($20/MBTU) could provide roughly 50 percent of the total energy requirements (20 MWhe) of a one- or two-family house. In Austria the roof area is about 300 km². Assuming that one-third is suited for solar absorbers, the upper limit would be 20 TWh for Austria as a whole, or 10 percent of its present demand for secondary energy. More realistic figures would be closer to 4 percent, however; to provide more than this one would have to go beyond such local applications.

A fairly detailed IIASA study indicates that in Austria an area of about 2500 km² could be available for solar power (*11*). This could provide the technical potential for producing 100 to 400 TWh/year, depending on local conditions, temperatures, and so on—a high figure indeed. However, the seasonal cycle has to be bridged, and this leads to large-scale storage requirements. The study concludes that not more than 60 to 80 TWh/year could be harvested if hydrostorage were used. Thus, even though Austria has many mountains and therefore enjoys this large storage potential, the total solar energy available is constrained by storage and not by land.

This constraint is much harder on most other Western European countries. It could only be overcome by the generation of a storable and transportable secondary energy carrier, which couples the development of large-scale solar power for base load purposes to the development of, for instance, a hydrogen technology. What the system costs will turn out to be eventually is not clear. In any event, the determining parameter ultimately will be the feasible rate of introduction should the capital costs be acceptable. Solar power on a significant scale is therefore a long-range option, say beyond the year 2020. It would therefore be prudent to allot to it not more than about 5 percent of the 3-TW energy demand assumed for the year 2000—to many observers this still appears a very big number.

A Strategy for Western Europe

In view of the discussion above, the following strategy seems appropriate for Western Europe.

1) After 1990 sharply increasing difficulties with energy imports should be expected; therefore *all* domestic energy sources should be developed.

2) Until the year 2000, perhaps 300 MTCE of hard coal per year could be made available indigenously. As much coal as possible should be imported. Despite the sometimes overwhelming market difficulties for coal today, it appears prudent to take long-range contracts or options for buying or possessing coal abroad. A reasonable target figure for such coal imports to Europe would be 300 to 400 MTCE/year.

3) Develop nuclear power to the greatest possible extent. A target figure of 500 to 600 MTCE, or 300 to 400 GWe, appears appropriate. At the same time, it is mandatory for Western Europe to develop the nuclear breeder as rapidly as possible and without delays. Appropriate steps must be taken for nuclear power to produce more than just electricity (*11a*).

4) All other renewable energy sources such as solar and wind power must be developed. The key parameter, besides capital cost, is energy storage. It does not appear prudent to expect more than 200 to 300 MTCE from such renewable energy sources by the year 2000.

5) Energy conservation must be given the same priority as energy supply. A conservation potential of perhaps 500 MTCE appears feasible by the year 2000.

6) Steps 1 to 5 will still leave Western Europe needing to import oil and possibly gas at a rate of perhaps 1500 MTCE/year by the year 2000. Economically and politically, it will probably be exceedingly difficult to do this. Prices of up to $25 and possibly $30 per barrel should be expected. Any long-range contract for supply or the possession of oil sources abroad must be made use of. Besides cost, the entrepreneurial, institutional, and political implications of going to unconventional oil resources must be kept in mind.

A Global Constraint

In the future there will clearly be a strong worldwide competition for energy sources. It is therefore appropriate to ask for the reasonable upper potential of global energy production in the next decades. In an IIASA paper for the World Energy Conference (*12*) we estimated this potential to be about 35 TW by the year 2030. Compared with today's figure of 7.5 TW, this means roughly a factor of 4.7, or slightly more than 3 percent growth per year averaged between now and 2030. On a global average this would permit not more than a 3.7 percent economic growth rate. Realistically, one should assume not more than a 3.2 percent upper limit for the latter. For comparison, the scenarios in the recent study by Leontief *et al.* (*13*) for the United Nations and the projections of the New Economic Order give such average growth rates as about 5 percent. The dilemma is that the developing countries will demand growth rates higher than the global average. Corresponding growth rates lower than 3.2 percent for the developed countries would further aggravate their balance of payments problems, which result from increasingly expensive energy imports. Instead, they will try to stimulate economic growth in order to partly compensate for the rising share of energy costs in their balance of payments. In other words, it is possible that the north-south confrontation will become worse. It is against this background that we finally conclude that *every* available energy source, including nuclear and solar power, must be developed as quickly as possible without any further delays. And against this serious background the problem of public acceptance must be assessed.

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