can be reproducibly monitored with time. The methods are based upon three principle assumptions. (i) Rate-limiting processes are uniform and function at roughly constant rates throughout the periods for which they are rate-limiting; (ii) the identities of rate-limiting processes do not change with a shift in temperature within the small test range; (iii) rate-limiting processes are affected in a roughly linear fashion by temperature shifts within the limited test range. Although no direct proof is presented that these assumptions are correct in every case, the data obtained by applying the method to *Dictyostelium* demonstrate that they are useful first approximations. However, the methodology is oversimplifying. Although we have treated a timer as a uniform process, it is quite possible and probable that in many cases timer "processes" are not uniform and may even represent sequences of events that exhibit different temperature sensitivities. It is possible to expand the methodology to test this possibility by performing temperature shifts at short interval times during the period preceding each stage when the timer for that stage is progressing. Such an analysis would test whether all portions of a timer are affected in a uniform fashion by a temperature shift.

Although I have used temperature as the environmental variable in this study, other environmental conditions can be substituted. However, conditions other than temperature may not be as pervasive for all regions of a cell or for all regions of a multicellular system. Methods other than environmental perturbations can also be used to specifically investigate timers. These include the use of both metabolic inhibitors and mutations that differentially affect the timing of stages in a developing system. The conditional methods presented have so far been applied only to *Dictyostelium*. The results are interesting and provocative, but it must be kept in mind that, because of the assumptions and limitations of the methods, the scheme for timer relationships is tentative. In view of the lack of other methods, the ones I have developed should be valuable in initial attempts at understanding the regulation of timing in developing systems. Evaluation of the general usefulness of the approach must await the application of the methods to a wide variety of developing systems.

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Energy Choices for the Next 15 Years: A View from Europe

C. Pierre L.-Zaleski

Summary. A European perception of the world energy situation and its likely evolution during the next two decades is presented. French energy policy is then discussed as a possible set of consistent choices that can be made to deal with the energy situation in a regional context for the next 15 years.

It seems appropriate to introduce a discussion of energy choices by two remarks. These remarks are general, obvious, and were made many times before; however, they seem to me so important that I will take some of the reader's time to stress them again.

First, in dealing with energy planning, it is necessary to remember the long delays that in this field separate a decision from its effects on everyday life—in other words, the inertia of energy. The delays in energy production may be on the order of 10 to 20 years between the start of research and the technical demonstration of a process, 10 to 30 years between technical and commercial demonstrations of a new system, 10 years between the decision to build and the start-up of a power plant, and 10 years between the beginning of exploration for oil, coal, or uranium and operation of the mine or oil field.

For energy consumption systems, there is also considerable inertia. For example, probably 60 percent of the buildings in France in the year 2000 will have been constructed before 1975. Therefore the new thermal insulation standard introduced in 1974 will apply to only 20 percent of buildings in 1985, 28 percent in 1990, and 40 percent in 2000. A new automobile model may be introduced after 5 years of study and design, sold for 5 to 10 years, and used for 10 years.

All this shows that an efficient energy policy should have continuity and persistence, should look far forward (20 to 25 years), and should not fluctuate with economic changes such as oil prices. Today's energy choices will have little or no effect on the real energy situation from now up to 1985 and perhaps longer. The energy situation in the year 2000 will, however, be almost fully defined by choices made in the next 15 years.

The second remark is about the specificity of each national situation and the simultaneous interdependence of local choices on each other and on the whole world economy. It is quite clear that demand, both quantitative and qualitative, and supply vary greatly from country to country and even from one region to another in a single country. Therefore each country and each economic region has to make its own choices on how to produce and how to organize the use of energy. It

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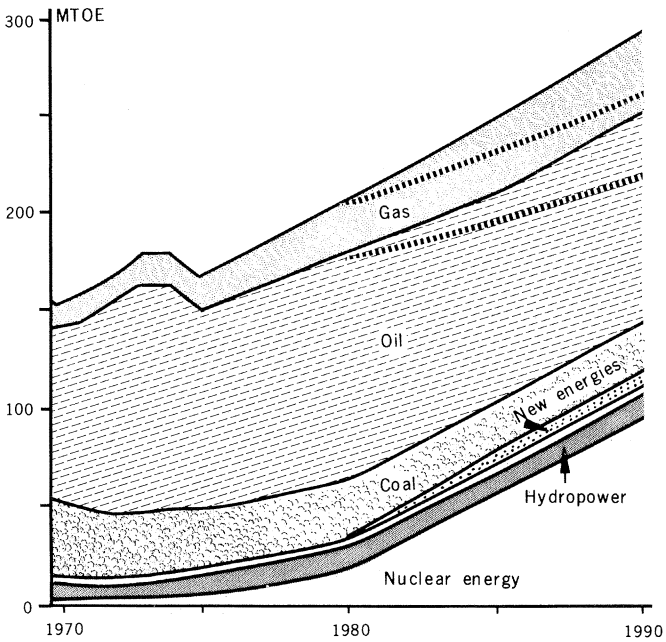

Fig. 1. Past, present, and expected future trends in French energy resources. Practically all the gas and oil and part of the coal used in France are imported. The dotted lines for gas and oil show new trends that take into account energy conservation efforts.

is also clear that the national situation is strongly influenced by the world situation. It depends, for example, on the availability and prices of raw materials (today oil and gas, tomorrow perhaps coal and uranium) and on the availability of new technologies and the experience of other countries with them.

In this article I will present a brief summary of expected world trends up to the year 2000 (*1*) that is based on many recently published studies, one of the most significant being the WAES (Workshop on Alternative Energy Strategies) study directed by C. L. Wilson (*2*). I will then describe the French situation and program for the next 20 years (*3*). As this program constitutes a relatively well-defined real (as opposed to speculative) set of choices, it may be of general interest.

World Situation

Energy demand. If we allow traditional trends to prevail, they will probably lead to an imbalance between demand and supply before the end of the century. For harmonious development of the economy, with progressively lower growth but without a brutal disruption of present trends, energy should be used more efficiently. A reasonable goal would be a saving of 20 percent by 2000 compared to the value projected from present trends. This will permit energy growth at a rate 1 percent lower than the growth of the economy. If this is achieved, energy consumption will still be 2 to 2.5 times greater by 2000 than it is at present. The developing countries will have an increased share of this consumption, about 25 percent by 2000.

Oil and gas. World oil production will reach a maximum of about 5 billion tons per year, compared with 3 billion tons in 1977. Based on present trends, this will be insufficient to meet the demand by 1990—or even earlier if some countries decide, for political reasons, to put stricter than technical limits on their production. Oil should therefore be reserved by the end of the century for uses that can hardly be accommodated by other sources of energy. Reserves of natural gas are probably of the same magnitude as oil reserves—250 billion tons of oil equivalent (TOE). Natural gas production was much lower than oil production in 1977—1.2 billion TOE—and could be expanded to reach about 3 billion TOE by 2000 provided large investments are made for the transportation of gas, mainly from the Middle East and the Soviet Union. Because of economic problems and the long delays involved in new technology, oil from shale and sands will not play an important role between now and 2000.

Renewable resources. There are still large hydro resources, especially in developing countries. Their use is expected to increase by a factor of 2 to 2.5 in the next 20 years, and they are expected to maintain their relative share of 5 percent of the energy supply. Other renewable energy resources, even if they become major contributors in the 21st century, will contribute only a few percent to the energy supply up to the year 2000; this is due to long development delays.

Coal and nuclear. To complement oil and gas supplies, which will be able to satisfy only about 50 percent of demand by 2000, it is necessary to develop coal and nuclear energy. We can hope to expand coal production by a factor of 2 to 3, but probably not more. For the noncommunist countries, most of this coal has to come from the United States, South Africa, and Australia. There will be great difficulties in achieving this increase, mainly related to consumption structures, which must be adapted; the difficulty of deep mining; the environmental problems of strip mining; and problems of transportation for the large fraction of this coal destined for Europe and Japan.

The total balance and possible contribution of coal suggest that it is also necessary to develop nuclear energy, which is now competitive with other sources of energy for electricity production. Today nuclear energy represents less than 2 percent of world energy consumption, and nuclear programs have slowed down in many countries because of the economic recession and the attitude of a vocal fraction of the public. As it is already too late to decide to build plants for operation in 1984, or in some countries even for 1990, we cannot expect that nuclear energy will contribute more than 20 percent of the total energy supply by 2000, and it is more likely to contribute 10 to 15 percent. This indicates that to avoid a painful crisis we have little time left to take appropriate decisions, and more importantly, to implement them. We must play all the cards we have.

French Situation and Program

The French energy situation is characterized by an extremely high level of dependence on imports. This, in turn, pushes us to develop more efficient ways to use energy. I think we are using less energy per unit of gross national product than any other industrial nation. This also induces us to make great efforts to develop technologies related to energy production. Our energy situation and programs are illustrated in Fig. 1, which shows the energy needs for France between 1970 and 1990. The three main directions of our energy program are (i) to use energy more efficiently, (ii) to develop technology for new resources, renewable and nonrenewable, and (iii) to use nuclear energy.

The first part of the program has as its goal a saving of 95 million tons of oil equivalent or 14 percent of total consumption by 1985. The saving already achieved in 1977 is 13 million TOE. These savings are or will be obtained by fiscal disposition (taxes, bonuses, and price policy), regulations (thermal insulation, speed limit, maximum temperatures, and support for public transportation), and technical improvements.

The second part has many aspects. For example, research and development to improve the status of conventional fuels includes gasification of coal (nuclear high-temperature reactors), technology for deep-sea oil prospecting and production ($300 million over 5 years is projected), and technology for enhancing the production from existing oil fields ($300 million over 5 years is projected).

Regarding renewable resources, the situation is as follows. Almost all practical hydro sites have been developed. The largest if not the only tidal plant in the world has been successfully operated for more than 10 years in La Rance. (Unfortunately, this energy is not very competitive at the moment.) The limited French geothermal resources are being developed, mainly for urban heating. Direct solar energy is also being actively developed. Solar furnaces have been operated for more than 10 years. A solar plant of 0.1 megawatt has been operated for 2 years, and another of 2 MW is under construction. Solar heating of water and homes is almost competitive in some southeast and south-central regions of France. Small solar units for remote locations have been manufactured and are being operated in Mexico and in countries in Asia and Africa. Increased attention is being paid to photovoltaic conversion, and an independent agency for solar research and development coordination was recently created. The solar R & D budget for 1977 was 5 percent of the total energy R & D budget, and in 1978 it rose to 7 percent.

Considerable efforts are being devoted to the development of energy from controlled fusion. France has one of the most powerful tokamaks in operation in Fontenay-aux-Roses and participates in the European project for one of the largest tokamaks now under construction, the Joint European Torus.

Nuclear Program

France has a large, aggressive and, I believe, comprehensive nuclear program. Nuclear energy is now competitive with other available sources for electricity production. The projected breakdown of electricity production costs for 1985, based on actual costs in 1977 and expressed in 1977 dollars, is: nuclear, 1300 megawatts electric, 19 mills per kilowatt-hour; oil, 700 MWe, 27 mill/kWh; and coal, 600 MWe, 26.0 mill/kWh. The largest factor in the cost for oil and coal is fuel; for nuclear, it is investment. Nuclear energy is almost 100 percent national (import-free), and with breeders it is practically inexhaustible.

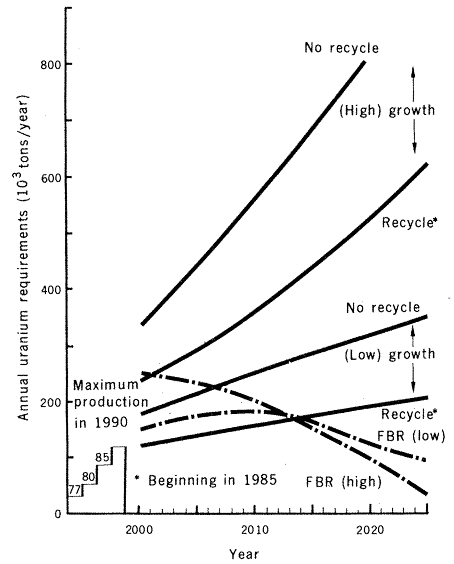

Fig. 2. Expected trends in annual world requirements for natural uranium and maximum annual uranium production (*3*). Even with a low-growth scenario, one can expect an imbalance between requirements and maximum production unless breeder reactors or at least plutonium recycling is implemented. Abbreviation: *FBR*, fast breeder reactor.

Finally, considering the global environment, nuclear appears to be at least as good a source for electricity production as coal and oil. These reasons have led us to a vigorous expansion of our nuclear industry and to a dynamic program. In 1985 nuclear energy will provide more than 50 percent of all the electricity produced and some 20 percent of the total energy consumed. In 2000 these numbers may be as high as 80 to 90 percent and 40 to 50 percent, respectively.

The French nuclear program is characterized by the use of plants of standard design, the establishment of a comprehensive full fuel cycle (closed; the necessary isotope enrichment and spent fuel reprocessing plants are in operation or under construction), and the development and implementation on a commercial scale of breeders as soon as possible but in any case during the next 10 years. At present France has 27 (900-MWe) pressurized water reactors in operation and under construction, four others planned, and four (1300-MWe) pressurized water reactors under construction. The installed power in committed reactors is projected to increase from about 7000 MWe in 1977 to about 36,000 MWe in 1985.

Our experience with the breeder is based on operating the 250-MW breeder demonstration plant Phénix for 5 years and building the 1200-MW near-commercial breeder plant Super-Phénix; 95 percent of the orders for components for Super-Phénix have been placed, and work on the site has been under way for 18 months. This experience indicates that liquid metal fast breeder reactors should be competitive with light-water reactors at a price of natural uranium of $50 per pound of U_3O_8, provided the breeder program is large, including a standard design, large series, and large fuel fabrication and reprocessing plants.

The rationale for developing breeder reactors may be summarized as follows. For the medium term (the year 2000), if nuclear energy is allowed to play a significant role, as we believe it will, there is a potential problem with cumulative world uranium requirements compared to world uranium resources, and even more with annual requirements compared to annual maximum production (*4*) (Fig. 2). This is based on the fuel needed for committed plants during their lifetime and on annually available resources. France will have to import a large fraction of the natural uranium it uses, and is therefore dependent on this strategic resource. The way to solve this problem and to permit nuclear energy to satisfy a large share of our energy needs is to stabilize the uranium demand by introducing commercial breeders on a large scale before 2000. Finally, the breeder may be used to get rid of the large amount of plutonium that will be produced by the end of the century.

Conclusion

An adequate energy supply may be one of the most difficult challenges for humans in the next decades. Probably the only reasonable solution that takes into account environmental aspects is to develop and make optimum use of all the different energy sources and to promote energy conservation. In the energy mix that results the role of nuclear energy will certainly be large, and, as nuclear technology is complicated, extensive international cooperation will be needed to make it widely available without compromising safety and economics.

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