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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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tensive exploration of the continental shelf could conceivably turn up major new fields and get them into production within a few years.

Neither extreme is foreseeable now, or what is more to the point, neither is being seriously planned for among public and private policy-makers, but that is not to say they are impossible or even improbable. In what follows, however, it is assumed that environmental objections can be gradually overcome, through adoption of safeguards and penalties, and that the philosophy of business as usual dominates energy deliberations.

The rush to lease offshore areas in the Gulf of Mexico continues, presumably reflecting industry's favorable assessment of the prospects for oil and natural gas in the continental shelf. Just how large offshore resources will turn out to be is one of the most sensitive questions confronting policymakers. R. R. Berg and his coauthors, like many who have studied the question, believe that domestic oil production can be increased nearly 50 percent by 1985 at present prices. Natural gas production might increase even more dramatically. If wellhead prices rise from about 25 cents per thousand cubic feet (the equivalent of oil at $1.50 a barrel) to 60 or 70 cents per thousand cubic feet, production could nearly double by 1985, according to M. Searl (formerly with Resources for the Future and now with the Electric Power Research Institute), who is completing a major study for the Ford Energy Policy Project. Both estimates assume a political consensus that would allow extensive development of offshore deposits.

Drilling on the continental shelf is not without serious environmental problems, although the danger of oil spills and pressure for industrialization of shore areas are probably no greater than would result from expanded oil imports. There is growing appreciation that offshore resources, if their development is carefully controlled, may have a lower environmental cost than any other major new source of energy now available. Thus, it is possible that the decline in U.S. production of oil and gas will be reversed before 1980, and that production will expand considerably in the 1980's. Until wells are drilled and discoveries made, however, it will be risky to count on more oil and gas.

Coal is increasingly cast as the fuel of the future, and establishment of a synthetic fuel industry based on coal is probably, as Squires suggests, in the national interest. For electric utilities and other industries facing a cutoff of natural gas, retrofitting gas-fired boilers with coal gasifying plants that produce low- or intermediate-Btu gas is already an attractive option, and orders are already being placed. Perhaps a dozen plants will be in operation by 1980. Many more gasifiers of advanced design, perhaps in combination with gas turbine generators, could be on line by 1985.

Other synthetic fuels from coal may not come as quickly. The first commercial-scale coal liquefaction plants are not scheduled before sometime in the early 1980's. Production of a high-Btu pipeline gas that could compete with natural gas is also not likely, according to present plans, before the middle 1980's.

For generating plants that burn coal directly, the choice is between the techniques for removing sulfur dioxide from stack gases which are summarized by Dunham and coauthors and the less well developed fluidized bed boilers. Stack gas cleanup, admittedly an inelegant solution to the air pollution problems of burning coal, may or may not prove the most economical alternative; its early introduction, if forced by regulatory agencies, will certainly delay introduction of more sophisticated methods. It seems certain that large numbers of stack gas scrubbers and a few fluidized bed units will be built before 1980.

How Soon Will Coal Be King?

Labor problems, uncertainty about environmental laws and their enforcement, and a heritage of technological backwardness are inhibiting rapid expansion of coal production and use. Nonetheless, coal production seems certain to rise, if gradually, and the 1980's will undoubtedly be a time of experimentation with new ways to mine and to burn coal in a variety of forms. But if offshore fields produce in a big way, it may be the 1990's or later before coal and synthetic fuels really come into their own. Considering the magnitude and variety of the environmental problems associated with coal that are still unresolved, the delay may not be a bad idea.

If oil prices remain high, shale oil may become a viable synthetic fuel on a time scale nearly comparable to that of low-Btu gasification of coal. A few plants based on surface mining of shale will probably be in operation as early as 1980, and production could expand rapidly thereafter. Nonetheless, the potential for surface mines is limited—peak production is unlikely to exceed about 1 million barrels a day, equivalent to half the capacity of the trans-Alaskan pipeline. Water shortages and environmental problems may restrict the scale of operations still further. Techniques to retort the shale in situ appear to be the major hope for a larger shale oil industry, and their successful demonstration could catalyze more vigorous exploration of this resource.

The number of nuclear power plants in operation is scheduled to increase fourfold by 1980. Short of a major accident or fuel diversion incident that could force political reconsideration, nuclear power will probably continue its rapid growth. Standardized designs and assembly-line production will probably greatly shorten construction times in the 1980's. The Atomic Energy Commission continues to forecast a uranium shortage that would impel a switch to a new nuclear technology —breeder reactors—sometime in the 1990's, but the balance of opinion seems to be in disagreement with that forecast. More likely, as Rose suggests, breeder reactors will not be economically competitive in this country until sometime in the next century. Fusion reactors, despite rapid advances in the underlying basic sciences, are also in the long-range category.

What amounts to a gold rush to look for deposits of dry steam is under way in much of the western United States, now that leasing of geothermal sites on federal land has begun. Quite a few wells, producing heat that will generate perhaps several million kilowatts of electricity, are expected to be in operation by 1980. Robson points to the reluctance of the oil industry, which is best equipped to find and develop geothermal sites, to enter the business in association with electric utilities as a constraint against rapid expansion. But if technical problems with using hot brine deposits can be resolved without greatly adding to the cost of geothermal plants, geothermal power will become an important regional supplement to coal and nuclear plants. By

the late 1980's, it is quite possible that techniques to tap dry, hot rock deposits may further expand the potential for geothermal power.

Applications of solar energy, although technically feasible in a few instances now, will be slow in coming. Some solar-heated houses are being built today, but significant installation of solar heating and cooling equipment (in, say, one-quarter of new construction) will probably not occur until the middle 1980's unless special incentives are provided. Production of synthetic fuels from wastes or other organic material, as Calvin suggests, will probably see only limited application in the near future. And widespread generation of electricity with sunlight, wind, or ocean thermal gradients is probably not in the cards until near the end of the century, if then. But the total impact of solar energy in its several forms will be more than negligible by the end of the century, and may become, as Wolf suggests, extremely important thereafter.

There are, finally, a number of constraints that could easily complicate the rapid expansion of domestic energy production in the next few years. Steel pressure vessels, used in oil refineries, nuclear reactors, and some coal gasifiers have been on back orders for years, and only a few companies in the United States manufacture them. Still fewer firms make the draglines used to strip mine coal. Other energy-related hardware, especially pumps and pipe, are in short supply. Demand for drill rigs affects the development of coal and uranium mines as well as geothermal, oil, and natural gas production. Shortages of skilled and unskilled labor—from engineers to coal miners—appear to be on the horizon. A major difficulty in expanding coal production will be finding enough train cars to haul the additional output. And, not least, there is a continuing scarcity of what might be called leadership at policy-making levels in government and in industry.

The inertia of the energy system and the time required to get new oil fields or new coal mines in production means that shortages of energy will probably persist for at least 3 or 4 years, unless Arab oil flows freely. Conservation measures are virtually the only means of easing the dependence on imports on that time scale without national mobilization. In the longer range, the energy problem in the United States does not look so formidable—we have lots of resources and lots of options. There are no technical barriers to an adequate and, if necessary, independent energy supply.

Two caveats are in order. What I have said applies only to the United States. Elsewhere, as Häfele makes clear, things are quite different. Second, the energy field is replete with forecasts that have not come true. So whether it is an early introduction of electric cars, a breakthrough in manufacturing techniques for solar cells, or an Atlantic coast oil strike rivaling that in the North Sea, I would be prepared for the unexpected.