Nuclear Power Plants—

Weighing Benefits and Risks

by HAROLD BROWN

CONSUMPTION of energy on our planet, and particularly in the United States, has risen at a rate that has become frightening in view of the limited resources of the earth. Despite embargoes and quintupled prices of imported oil, we have not yet focused on the realities of current shortages, the probabilities of energy famines, and the need both for conservation and for developing new or expanded energy sources. I believe that what happens about these energy sources—and to economic development in the U.S. and the world during the next century—will be determined largely by what we do in the next decade about nuclear energy.

No other energy source is subject to the variety and severity of controversy to which nuclear power is currently exposed. The issue is not merely the extraction of raw material, nor even inhibitions on the operation of power plants. In some cases the proposals would virtually forbid nuclear generating plants altogether. California's ballot this month has the best-known proposal, and its provisions are highly restrictive. Twenty-seven other states also have anti-nuclear legislative activities or voter initiatives.

The uncertainty as to what limitations are to be imposed in terms of environmental impact, or of safety, prevents a sensible design, development, and production schedule, greatly interferes with raising capital, and disrupts efforts to foresee needs for transmission and distribution of electrical power. However, during the next decade, decisions are going to have to be taken either consciously or by default on the sources of energy that will have to be used during the following 50 years. A central choice is the degree to which nuclear energy should be employed, and that will depend partly on public attitudes and on the ability to make political decisions.

The situation is extremely complex, but there *are* some key questions whose answers should determine policy in this matter. I believe that only when these are understood can public attitudes be informed ones, and only then can even a courageous leadership make the appropriate decisions.

There is clearly a connection between energy consumption on the one hand and economic and social well-being on the other. Quality of life includes GNP, pollution levels, and many other components. But specifically at issue here, in the observed connection between per capita GNP and per capita energy consumption, is: Which is cause and which is effect?

I conclude that each is both. In particular, there is a considerable waste of energy in homes and offices. On the other hand, for industrial production and probably for agriculture, as well as for much of the service sector, marginal returns on energy use are high. The value and productivity of labor in those areas are highly dependent on per capita energy consumption.

Reduction of consumption in existing residential and commercial structures is feasible, and so is an even greater reduction (perhaps 30-40 percent) through sensible redesign; in manufacturing and agriculture possible reduction is almost certainly less. Taking the economy as a whole, we may have a 25 percent or more

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cushion of waste. By increasing efficiency and by lowering consumption for marginal use, much of what would otherwise be necessary growth in energy requirements can be replaced during the next couple of decades without any substantial loss of economic well-being.

Perhaps we can thus cut the per capita U.S. growth rate in half—from 4 percent to 2 percent per year for total energy, from 8 percent to 4 percent in electrical energy—in the 1975-2000 period. However, even the reduction during 1974-75 in the rate of annual growth of energy consumption per capita to about half its former value is in substantial part responsible for the current—or recently concluded—recession.

There is, I believe, no acceptable way to take care of our economic needs for the next 50 or 60 years through energy conservation alone. We will have to find other sources both to meet increased needs and also to replace much of the present consumption of oil and natural gas, which together now comprise over 75 percent of the U.S. energy consumption mix. To anticipate a bit, I am convinced that the only realistic sources until well into the next century are fission reactors and coal.

In the U.S., and in the rest of the developed world, a rather modest rate of growth of per capita energy consumption can allow or even improve economic well-being. But anything other than a Malthusian solution to the inhuman poverty of the fourth world will require a large increase in per capita energy consumption. And total world reserves of fossil fuel won't even come close to providing the necessary energy base.

Nuclear energy is not a forseeable substantial mobile energy source. For these uses, either natural or synthetic hydrocarbons are by far the most advantageous, but the world's supply of the natural ones will probably be nearly gone within the next 30 to 35 years. Synthetic fuel from coal, shale, or tar sands may begin to be available then or earlier, but it will have to be saved for use in mobile power plants (autos, airplanes, etc.) and for feedstocks in petrochemical production. Indeed, I expect such restriction of its use to take place well before the end of this century.

For fixed power plants, coal and uranium are the principal sources available at least up to the year 2000. Sufficient reserves of each exist within the United States to supply the needs at present rates of stationary power generation beyond the year 2000, assuming that we go to a 50-50 mixture. The U.S. has about one-quarter of the world's supply of coal, enough for more than 200 years supply. Even without a nuclear breeder cycle, a comparable supply of energy exists in native uranium.

At least three other energy sources are possibilities. The first is geothermal energy, which can and should some day provide a small portion of the world's energy.

Solar power is a large potential source, but unfortunately it is at a very low level of concentration. However, it can soon be used effectively and at a reasonable cost to heat water and to heat and perhaps cool homes and offices in sunny portions of the world. The concentration of the sun's rays over large areas to produce high-temperature thermal energy, and hence electricity, through boilers or turbines is more distant in time. Direct conversion into electricity is further off still. I do expect that—by the end of this century or early in the next—solar methods would be able to provide perhaps 5 percent of stationary energy production.

The energy from controlled nuclear fusion is a fair prospect to begin playing a part in stationary power production early in the next century. Only now, I believe, are we within a decade or so of showing the feasibility of a nuclear fusion machine that puts out more energy than it consumes. Therefore, we have only just begun to consider the engineering problems that go with fusion plants. My own judgment is that these difficulties will approach those of fission. The environmental problems (including radioactivity) and even those of international control will also be far from negligible.

Thus, early in the next century, solar energy, and geothermal and fusion energy will just have begun to contribute to stationary power plant generation. Other possible exotic sources of energy also exist, but even the possible ones can have no significant effect during this century. The coming generation's needs will have to be powered either by fission energy from uranium, by coal, or by a combination of the two. These two are therefore a natural pair to compare in terms of economics, availability, and environmental and other hazards. Both uranium and coal are plentiful, but not unlimited, within the United States, so there are advantages to preserving coal for the production of synthetic fuel (liquid and gaseous) and for hydrocarbon feedstocks. To expand the contribution of uranium to central-station electric power production will take a considerable effort, but it is feasible.

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At present about 8 percent of U.S. energy is generated in nuclear plants; this corresponds to less than 2 percent of our total energy consumption. The Energy Research and Development Administration's projection is for 25 percent of electric power to come from nuclear plants by 1985. I think nuclear energy could provide well over half of the electric power generation by the year 2000. Moreover, I believe that this can be reached with little or no operation of breeder reactors.

Nuclear breeders are feasible, but particular designs may well take 15 years or more to prove out, and an operating cycle of about a decade is required to double the usable fuel in a breeder reactor. The price of uranium ore is $24 per pound (triple its recent value), which makes its contribution to the cost of nuclear energy a bit more than 2 mills per kwh. The price could go to $100 per pound without markedly affecting the economics of nuclear power. However, such a price would greatly increase the availability of uranium, which is a key factor in the question of when and whether breeders will be needed to carry us to the fusion and/or solar age.

Space here does not permit a detailed economic comparison between coal-fired plants and fission reactors. Past nuclear capital costs have been close to those of coal-fired plants (but various hidden subsidies were present). The comparison is complicated by: the recent rapid rise in capital costs of coal-fired and especially of nuclear plants; the effect of construction time on the interest costs associated with construction; the difficulty of extrapolating these trends to the future; the uncertain added costs of environmental and safety precautions for both; and the (inverse) linear effect on capital costs per kilowatt-hour of the fraction of the time that a plant operates at full power.

My examination of capital, fuel, and operating cost factors suggests to me that the costs per kilowatt-hour of coal and nuclear power will be fairly close late in this century. The most probable cost for nuclear power appears somewhat lower, but the costs of added safety precautions that may be imposed could reverse that relationship.

In the light of these economic and other factors, I place a high priority on the need to consider various aspects of safety in the operation of power-producing converter reactors.

The crucial issue of safety falls, for nuclear reactors, into four categories: (1) health and safety for workers and surrounding population in normal operation; (2) safety against and consequences of release of radioactivity in some form of reactor accident; (3) problems of processing and of long-term storage of the highly radioactive spent fuel; and (4) the problem of diversion of enriched uranium or plutonium to weapons purposes.

The first of these, the environmental effect of normal operation, is actually far less than it would be for a plant burning fossil fuels at the same site. The chemical pollutants (hydrocarbons, oxides of sulphur, nitrogen, carbon) are absent. Waste heat is comparable. And nearly all radioactivity is contained on-site.

Each of the remaining three categories of safety issues is a serious one, but—with the possible exception of the last—I think they are all manageable.

Extensive (and conflicting) calculations have been made about the probability of reactor accidents that could release into the atmosphere various amounts of radioactive by-products—not by the reactor blowing up, but by its melting down. We are not sure what the effects would be on the population of small doses of radioactivity, administered over many years, resulting from an accident, but there is a generally accepted upper limit.

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For a typical population density in the area extending to 500 miles from the nuclear plant, this upper-limit assumption indicates that a very severe but also very rare accident could produce, over the 50 years following such an accident, as many as 10,000 long-term deaths from radiation if individuals did not move out of the area and if the difficult task of decontamination was not carried out. This is a large absolute number, but it looks rather different if one multiplies it by the one-in-a-million estimates of probability of such an accident per year of operation that some analysts have made. There have been no meltdown accidents at all. Experience of actual operation approaches the one-in-a-few-hundred probability level as an upper limit—none has happened in that much operation, even in terms of much smaller release of radioactivity. It is, in fact, very hard to get a good estimate of the probability of such unlikely accidents. However, the fraction of the radioactivity emitted in any accident can probably be reduced by such actions as placing the nuclear reactor underground.

Should such a very severe but very unlikely accident occur, the probability that an individual who continues to live in the exposed region will die of cancer induced by radiation from the accident is, making a worst-case linear assumption, one chance in a thousand, with the cancer manifesting itself at some time during several decades following exposure. This is to be compared with a present probability of about one in five—200 times as much—of dying of cancer induced by other natural or man-made causes.

It appears almost certain that the sulphur content of burning coal in central power stations, even if desulphurized coal is used, is much more hazardous than the effect of nuclear plants in normal operation. The same relation may apply to accidents at a fossil fuel plant compared with those at a nuclear plant. We can't say for sure because the long-term effects of low-level exposure to sulphur-dioxide (or of the sulphuric acid to which it can be converted in the presence of ozone particulate matter in the atmosphere) are even less well known than the effects of small quantities of radiation. Thus, there are unanswered questions about accidents and safety. But comparison with the effects of other energy sources available during the next 50-75 years suggests that nuclear energy need not be more dangerous.

The problem of finding an acceptable storage method for spent nuclear fuel that will be safe for thousands of years is not a trivial one. Yet there are some methods (including storage in salt domes) that appear very likely to work.

Meanwhile, one should not ignore the possible long-term effects of expanded use of hydrocarbons. Their combustion produces carbon dioxide, which has some risk of producing a greenhouse effect, increasing earth's surface temperature, ultimately melting the icecaps and raising the sea level by 100 feet, with catastrophic effects. This is not demonstrably more unlikely than the biggest nuclear reactor accidents, and would be much more severe in its consequences.

The most serious problem arising from nuclear reactor power is that of nuclear proliferation. By this I mean the acquisition of quantities of weapons-grade fissionable material, sufficient to produce nuclear explosives, by countries not now possessing them, or by non-governmental groups of terrorists, gangsters, or others. This is a severe threat to the peace and security of the world and of each country in it. If the U.S. could eliminate or greatly decrease this threat by foregoing or delaying construction of more nuclear power plants, I think we should seriously consider doing so, using coal, and trusting that pure fusion or solar energy will become economic before U.S. coal is used up.

But when one looks at the rest of the world, this approach appears rather naive. Western Europe has about one-fifth as much coal as the U.S., Japan virtually none. For those nations to delay massive use of nuclear reactors into the twenty-first century is economic suicide—which they won't commit. Therefore, trying to forbid reactors, or abstaining from using them in the U.S., will surely fail to prevent nuclear proliferation. We should work instead on rigid control. In that attempt, I think we have substantial leverage. This is our best real hope—though far from assurance—of keeping nuclear weapons and dangerous radioactivity from those even less responsible than their present possessors.

The "vendor nations"—the Soviet Union, the U.S. and Canada, France, Germany, Britain, and Japan—have common interests in establishing close controls to prevent unauthorized possession. Any solution, of course, will have to be principally a political one. The problem can be solved, if at all, only by cooperation among nations. In cases where the reactors or fuel are made in the U.S. or with our help, we can insist—and put pressure on the other vendor nations to join us in this insistence—on limiting any processing facilities for the spent, plutonium-containing fuel to internationally supervised regional (not national) plants, preferably in countries that already have nuclear weapons. The availability of, and the will to use, very strong political sanctions against countries that refuse to accede will be an important factor.

For this approach to work, it may be necessary to postpone the use of breeder reactors, which depend on recovering plutonium. A small risk in doing so is that we might run out of coal *and* medium-grade uranium ore before we can make available enough power capacity from solar energy and pure fusion. I would incline toward going slowly on the operation of plutonium recycle plants and of breeders while we seek rigid controls against proliferation. But I would go ahead with their development. This would allow breeders to be activated some decades before other fuels run out, if an energy catastrophe is then judged more dangerous than the increased risk of diffusion of plutonium.

Since only technologies now in being (coal, oil, natural gas, solar energy for heating and cooling but not for electricity, converter reactors) can give us substantial quantities of energy by the year 2000, now is the time to pursue strong development programs in a number of other areas. These include fusion, solar energy, geothermal energy, and fission breeders—all for stationary electric power production; and conversion of tar sands, shale, and coal to liquid and gaseous hydrocarbons. The nuclear and other energy industries and the utilities cannot successfully convince the public of the need for such development programs on their own. Their views are understandably discounted as being influenced by their own interests. However, if what I have said is a sensible way of tackling the problem, then explaining it ought to be an educational process that is within the capacity of our business, governmental, educational, and scientific leadership.

We need to pay more attention to the problem of understanding hazards in general. Our society has not reached agreement on how to weigh the benefits against both such general risks as proliferation and the individual risks of serious accidents of very low probability but high potential damage. We have not determined accurately (though we have a fair upper limit on) the effects of low-level, long-time exposures to nuclear radiation and (less well) to chemicals or other environmental products. Most important, we lack an effective framework—academic, business, and political—for the decision-making process itself. Creating it will not be easy, but only when it exists can our arguments at least be about the right questions.

Among these matters, questions of the need for nuclear plants and how (and whether) they can be made safe will probably be the first to be decided. The ballot initiatives that have been advanced strike me as not the right way to make the decision. But the debate that they inevitably initiate is a vital opportunity to influence in a positive way our pattern for deciding future questions of new technology, economic need, environmental health, and other hazards—as regards not only nuclear energy but coal, other energy sources, and other issues as well.

I think that these decisions can be taken so as to be consistent with resource conservation, to give as good assurance of environmental safety and international security as any practical alternative, and to preserve and even raise—slowly—the standard of economic well-being of mankind. □