Energy Options: Challenge for the Future

The subject of energy concerns both environmentalists and economists these days. Indeed, there is a growing consensus among many scientists, industrialists, and elected officials that providing an adequate supply of energy in acceptable forms will be one of the most important technological challenges facing the United States in years to come. As conventional sources of energy are depleted, as the economic penalties of importing large quantities of fuel become higher, and as social constraints on the production and use of energy multiply, increasingly sophisticated and costly means of meeting our energy needs will be necessary.

Many substantial energy sources appear to be available. To realize their potential, however, will require substantial scientific and engineering efforts. Because it takes a long time to develop and introduce new technology, a far-sighted national policy is essential. But with the exception of the federal government's efforts to develop nuclear energy, remarkably little research is being done toward improving the use of existing energy sources or developing new sources.

Many different technologies are now receiving attention as possibilities for the future. A series of forthcoming articles will examine the proposed technologies, the technical uncertainties, the environmental consequences, and the economic potential of the major energy options. Some of these technologies are new and essentially untested, so that detailed analyses of their advantages and disadvantages are still not possible. But informed estimates, where available, will be included.

There is no lack of ideas for new sources of energy or for means of exploiting them. Among the options being considered are nuclear, solar, and geothermal energy, as well as extensions of fossil fuel resources. The Atomic Energy Commission predicts that breeder reactors, on which nuclear fission will ultimately depend, will be commercially available by 1985. Also by that date, according to one assessment (*1*), it should be possible with increased federal spending and leadership to develop the following impressive array of nonnuclear technologies.

1) The commercial use of solar energy for heating and cooling homes in many parts of the nation, and perhaps some form of central station solar power.

2) Commercial geothermal energy in significant quantities in the western half of the country.

3) Commercial gasification of coal to supplement supplies of natural gas.

4) A commercial shale oil industry producing upward of 1 million barrels per day and capable of rapid expansion.

5) A fluidized bed combustion chamber to burn coal in a power plant without emitting sulfur and other pollutants into the air.

6) Large gas and steam turbines operated in a combined cycle to generate electric power with a minimum of pollution and with improved efficiency.

7) Dry cooling towers to permit power plants to be located at remote sites without using water for cooling.

8) A commercial fuel cell for total energy installations that would be more efficient than existing means of energy conversion.

Fossil fuels are likely to remain the dominant source of energy for most of the remainder of this century, despite diminishing supplies and expected higher prices, but improved methods of combustion of coal and the gasification of coal and oil could help to ameliorate the air pollution now associated with use of these fuels. Higher prices for petroleum may spur the development of artificial fuels. Electric automobiles for urban use would allow electricity from nuclear energy to be utilized for transportation, thus reducing the need to import oil.

Of the new energy sources, nuclear energy is the most advanced. More than 25 nuclear power plants are in operation, another 50 are under construction, and development of the breeder reactor is in progress. But at the Geysers in northern California, geothermal energy is already being used to generate electricity, and there seems no doubt that naturally occurring sources of steam and hot water can be rapidly exploited. Still to be demonstrated are proposed methods of tapping the much larger geothermal resources of subterranean hot rock. Solar energy appears close to becoming a practical means for home heating and cooling. Efforts are under way to develop solar-thermal plants for generating electricity. The prospects for achieving controlled thermonuclear fusion have improved rapidly in recent years; the scientific feasibility of laser-induced fusion in particular now appears likely to be put to a test within several years, although the design of practical power plants remains some distance in the future. Even the possibilities of extracting energy from the wind or from temperature differences in the oceans—sources that represent indirect forms of solar energy—are attracting renewed attention.

Direct solar radiation is man's largest energy resource (Tables 1 and 2), although its diffuse character requires large areas to capture significant

Table 1. Estimates of depletable energy resources in the United States. The resources are given in units of U.S. annual energy consumption (6.6×10^{19} joules); the figures in the table are equivalent to the number of years that the resource would last, if all energy came from that source, at current rates of use. Recoverable resources include those known and *now* available; total resource estimates include expected off-shore deposits and do not necessarily represent recoverable amounts of energy (*2*).

Resource	Recoverable	Total
Fossil fuels		
Coal	125	1300
Petroleum	5	280
Natural gas	5	110
Oil shale		2500
Nuclear fission		
Conventional reactors	2.3	15
Breeder technology	115	750
Nuclear fusion (*3*)		
Deuterium-deuterium		$\sim 10^9$
Deuterium-tritium		$\sim 10^6$
Geothermal heat		
Steam and hot water	0.2	> 60
Hot rock		>600

Table 2. Estimates of renewable energy resources in the United States. The renewable resources are given in units of the current U.S. *rate* of energy consumption (6.6×10^{19} joules per year); the numbers in the table indicate the *proportion* of current U.S. energy needs that the resource could supply for an indefinite period (*4*).

Resource	Continuously available
Solar radiation	740
Wind power (*5*)	5
Sea thermal gradients (*5*)	>6
Hydropower	0.14
Photosynthesis	0.23
Organic wastes	0.1
Tidal energy	0.1

amounts of energy. Fusion resources are also quite large, although the exact magnitude depends on whether the deuterium-deuterium reaction or the more easily achieved deuterium-tritium reaction is ultimately the basis of operating reactors. With present technology, fission is an extremely limited resource; breeder reactors that can convert, for example, uranium into fissionable plutonium will be necessary to exploit the fission option on a large scale. Naturally occurring resources of geothermal steam and hot water are also limited. More geothermal energy is contained in hot rock beneath the earth's surface, the amount increasing with the depth that can be drilled economically.

Although most observers expect solar, geothermal, fusion, fission, and fossil energy resources to provide most of man's energy needs, still more unconventional sources have potentially large amounts of energy. Winds within 80 meters of the ground are estimated to contain about five times the energy that we now use, and temperature differences in the sea also provide a significant reservoir of energy.

Research and development efforts have been concentrated on only a few energy technologies, most especially nuclear fission, which accounts for more than half of the federal energy budget (Table 3). Nuclear fusion has also enjoyed substantial support, despite the long-range character of this option, while solar energy receives less than 1 percent of the roughly $600 million that the federal government spends on energy research. Relatively little is being spent on improving fossil fuel technologies, despite the immediacy of the need, and much of the existing research program seems to be fragmented and without effective leadership. A substantial, and not easily determined, amount of research on energy technologies is carried out within industry. But in view of the unavoidable financial risks and long lead times associated with new energy technologies, it is not surprising that the energy industry has in recent years been generally unwilling to undertake the development of new technologies, except under pressure from and with the support of the government.

The various energy options, if they were to be developed, would affect the present energy system in different ways. The economies of scale for both fossil-fueled and nuclear power plants, for example, are such that both have tended to grow larger—many now being built have a generating capacity of 1000 megawatts. The power plants envisioned for fusion processes that depend on magnetic containment of the plasma would be still larger, from 2,000 to 10,000 Mw, leading to a very centralized energy system and perhaps necessitating superconducting transmission lines to carry the enormous amounts of electricity. In contrast, power plants to exploit laser-induced fusion could plausibly be built with generating capacities as small as 100 Mw. Most geothermal plants are also expected to be of the 100 to 200 Mw size, which would necessitate a more decentralized energy system. The optimum size for solar-thermal power plants is not yet known, but some observers believe that these too will ultimately be relatively small, compared to modern fossil-fueled plants.

Table 3. Federal energy R & D funding proposed for fiscal year 1973, subject to approval by Congress.

Item	Budget ($\$10^6$)
Fossil fuels	136
Nuclear fission	356
Nuclear fusion	65
Solar energy	4
Geothermal energy	3
Related technologies	55
Total	622

The form in which energy is used may also have a considerable influence on the relative advantage of the different energy options. Over long distances, it is considerably less expensive to transport gas in a pipeline than to transmit electricity over existing networks. Large, centralized power stations could be built in isolated locations, according to one proposal, and their output used to produce hydrogen or other gaseous fuels which in turn could be piped to users. Decentralized power stations, on the other hand, could be built as multipurpose facilities, and their waste energy could be used for industrial or residential heating, or for desalting water. Fuel cells that operate on artificial fuels, or perhaps eventually photovoltaic solar cells, could ultimately decentralize even the generation of electricity.

Energy is the basic natural resource, and in 1970 Americans used a prodigious 6.6×10^{19} joules, more than a third of the world's consumption. The rate at which the United States uses energy is growing rapidly, has doubled in the past 20 years, and is now about 2 billion kilowatts—the equivalent of the output of more than 2000 large power plants running at full capacity. About 96 percent of this energy comes from fossil fuels: petroleum, 43 percent, mostly for transportation; natural gas, 33 percent; and coal, 20 percent. Hydroelectric energy accounts for about 3 percent of present production, and nuclear energy for about 1 percent. The pattern of energy use is changing rapidly, and in recent years, the use of natural gas has increased more than twice as much, proportionately, as total energy consumption.

In 1970, 25 percent of the raw energy resources consumed in the United States were used to generate electricity, and this percentage is increasing rapidly. Transportation also consumed about 25 percent of total energy production, industry accounted for 30 percent, and residential and commercial uses, largely heating and cooling, consumed 20 percent. Of the energy consumed to make electricity, roughly a third is actually converted into electric power and the rest into waste heat. About half of the electric power is consumed by industry, and half goes to residential and commercial use. Despite the inefficiencies inherent in electric energy, projections are that the demand for electricity will quadruple before 1990.

Research priorities on energy technologies are sadly out of balance, and, according to many of those who have examined the central role that energy plays in our economy, grossly underfunded. Major reordering of funding patterns for energy research, and possibly of the federal organizations that administer energy research, may well take place within the next few years. The various energy options and combinations of options, it is fair to say, have not been well studied for their impact on the overall energy system. Nor are the relative advantages of different options firmly established. The problems involve difficult social, economic, and technical choices, and appear to be worthy of more extensive attention than they have yet received.—ALLEN L. HAMMOND

References and Notes

1. S. D. Freeman, testimony before the Senate Committee on Interior and Insular Affairs, 7 June 1972.
2. Adapted from "Energy resources of the United States," *U.S. Geological Survey Circular*, No. 650 (Washington, 1972), except as noted.
3. J. Tuck, Los Alamos Scientific Laboratory, Report No. LADC 9519 (1970).
4. C. Starr, *Sci. Amer.* **224**, 37 (September 1971), except as noted.
5. A. Eggers, testimony before the Senate Committee on Interior and Insular Affairs, 7 June 1972.