

New Technology in the 80s

A panoramic view of emerging technologies likely to predominate in the 1980s; licensing implications

BY WILLIAM P. O'NEILL*

No one can forecast where and how technology will grow most fruitfully in the 1980s. But what follows is an attempt to view the whole forest, or at least a number of the tallest trees between here and the horizon, rather than enjoying the familiar comfort of our own particular parts of the woods.

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There is little doubt the most extensive technological development of the next decade will concern the energy problem. As virtually the most energy-intensive people on earth, Americans should be more motivated than most to address this global problem. (Figures 1-3). A highly recommended study by the National Research Council (NRC)¹ concludes that the solution to the well known energy problem "is not simply to produce more energy and not simply to conserve, but rather to find a new economic equilibrium between supply and demand. Higher prices are inevitable, and the nation must take advantage of the resulting opportunities for both enhanced supply and greater efficiency in energy use." This is an invitation to all sorts of innovators.

The NRC assigns highest immediate priority to energy conservation, with the generalization that throughout the economy it is now a better investment to save a BTU than to produce an additional one. This provides substantial incentive for product innovation and capital replacement in all sectors. Computerized "thermostats", novel insulation schemes and more efficient motors are but a few of the types of products being promoted.

The NRC predicts that technical changes in energy efficiency based on advances in currently available technology alone — but without any major breakthroughs — could reduce the ratio of energy consumption to GNP to half its present value over the next 30 to 40 years. However, this conversion is "sensitive to the prices assumed and a result of this magnitude is attainable only if the prices for energy increase more rapidly than is probable in a market at equilibrium." In any event, the NRC Demand and Conservation Panel studies indicate the growth of demand for ener-

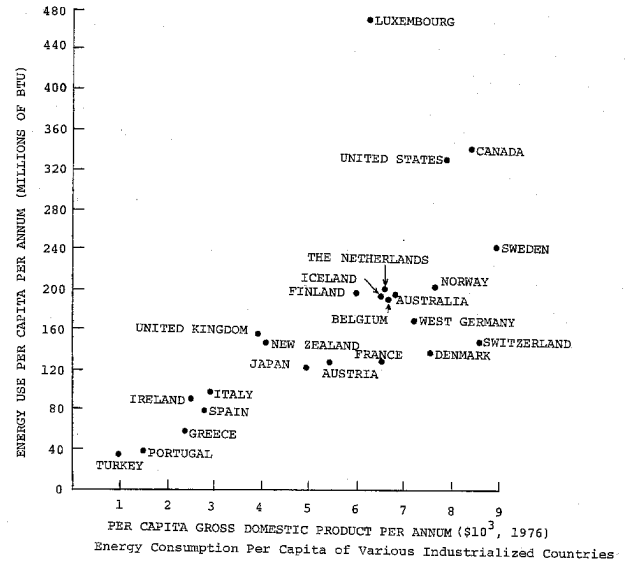
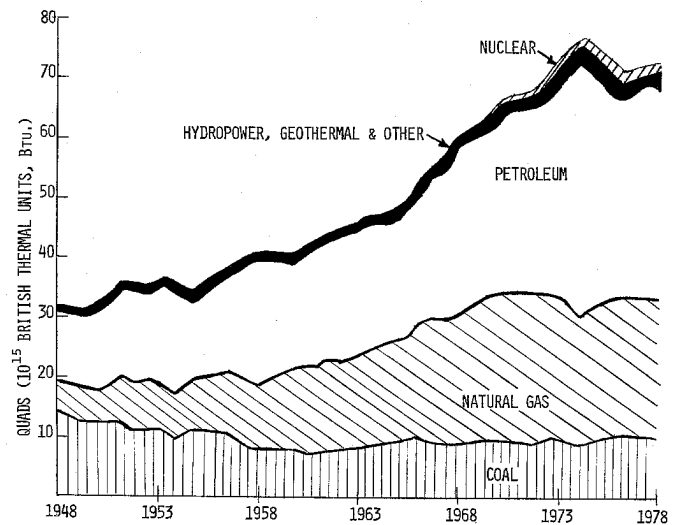


Figure 1

gy in this country could be reduced substantially — particularly after about 1990 — by gradual increases in the technical efficiency of energy end-use and by price-induced shifts toward less energy-intensive goods and services.

The NRC reported:

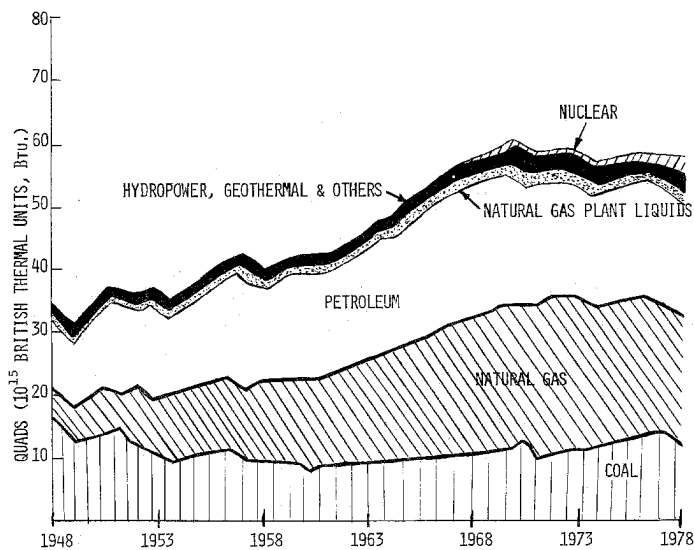


ENERGY CONSUMPTION IN THE U.S. BY ENERGY SOURCE

(Adapted with permission from reference 1, page 2.)

Figure 2

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ENERGY PRODUCTION IN THE U.S.A. BY ENERGY SOURCE

(Adapted with permission from reference 1, page 3)

Figure 3

"The supply of liquid fuels — gas and oil — which provide about 75% of this nation's energy will be critical in the 1980s to '90s. Petroleum supplies worldwide will be severely and increasingly strained, as world production approaches its probable peak at the end of the century. . . . For the intermediate term, conservation of liquid fuels is an urgent necessity." The NRC recommended that, second only to conservation, priority be accorded to domestic oil and gas exploration and development, along with encouragement of a strong synthetic fuel industry.

U.S. Consumption

The U.S.A. accounts for almost 30% of world oil consumption, and imports provide about half the oil consumed here — one-fifth of our primary energy comes from foreign oil. Domestic oil production peaked in 1970 and by 1978 fell to 3.2 billion barrels (about 17 quadrillion BTUs, quads). Under the policies prevailing until recently, the NRC projected domestic production of oil would fall from 20 quads in 1975 to only 6 quads in 2010 (U.S. oil consumption in 1978 was 37.8 quads). Moderately enhanced conditions for oil production (including removal of price controls, accelerated offshore leasing and somewhat advanced exploration and production technology) would bring production in 2010 to 16 quads. However, a national commitment could only raise the level in 2010 to 18 quads. The NRC concluded, with some dissent, "under no plausible conditions does it appear possible even to maintain current domestic oil production, much less increase it".

Domestic natural gas production peaked in 1973 at 21.7 trillion cu. ft., and declined about 10% since then to a level which corresponds to about 18.5 quads. Gas production projections by the NRC Supply and Delivery Panel showed an even more severe decline than oil projections. However, the dissent was even more extensive on this forecast.

Some recent estimates (such as those of the Electric Power Research Institute) of natural gas production

by 2000 have run as high as 30 quads (in contrast to the range of 5 to 16 quads projected for 2010 under the various NRC Panel assumptions). These estimates are based on suggestions that Devonian shales, coal seams, and geopressurized brines could be tapped for "unconventional" natural gas. Furthermore, worldwide a great deal of gas is being flared or reinjected now, rather than marketed.

Oil shale is not expected to prove to be a major source of energy, despite the huge energy content of the domestic resource, according to the majority of the NRC committee members, because:

1. The resource is concentrated in a very small, relatively primitive region where large-scale development is likely to face resistance on environmental grounds.
2. Water supplies are a serious constraint.
3. The amount of solid waste that must be handled is very large relative to the energy extracted, even with *in situ* processing.

Nevertheless, they anticipate that oil from shale will probably become economically competitive earlier than other synthetic fuels.

Coal Resources

Coal is the most abundant fossil fuel. The total domestic resource is roughly one-fourth of the world coal resource of 300,000 quads. Each year we now consume less than 0.3% of the 6,000 quads currently considered recoverable from our domestic coal — 14 quads annually. In contrast, the nation will extract about 10% of its 420 quad recoverable reserves of oil and natural gas this year. Nevertheless, the numbers do not tell the whole story. "Coal use is limited, not by reserves or production capacity, but by extraordinary industrial and regulatory difficulties of mining and burning it in an environmentally acceptable, and at the same time economically competitive manner," as the NRC puts it. "Domestic coal production capacities today exceed domestic demand, and this may well remain true until the end of the century."

The NRC's expectations with respect to the commercial introduction of advanced technologies for the use of coal are summarized in Table 1. These include methods for improved combustion, gasification technology that is in hand, and some pretty exotic possibilities, as well as the much talked about synthetic gas and liquid hydrocarbon technologies. The goals for a National Coal Policy recommended by the Committee on Nuclear and Alternative Energy Sources, are outlined in Table 2.

One outcome of these deliberations was the creation of the Synthetic Fuels Corporation, at the end of June 1980. It has the authority to commit some \$82 billion to foster the creation of a new industry by 1992. It has a 1987 goal of 500,000 barrels per day, and by 1992 aims for 2 million barrels per day of liquid fuels — about 30% of today's imports. (In addition, another program administered jointly by the Departments of Energy and Agriculture has \$1.5 billion to aid developments to achieve conversion of biomass to fuel with the aim of producing enough ethanol to replace 10% of the nation's gasoline by 1990.)

Achievement of these goals poses formidable problems, beyond those common to all government programs. Fluor, the engineering company that is build-

ADVANCED TECHNOLOGIES FOR THE USE OF COAL

(Adapted with permission from reference 1, pages 22 & 23)

TECHNOLOGY	CHARACTERISTICS	STATUS OF DEVELOPMENT	POSSIBLE DATE FOR COMMERCIAL INTRO.
ATMOSPHERIC FLUIDIZED-BED COMBUSTION	APPLICABLE TO SMALL POWER PLTS. AND SMALL-SCALE INDUSTRIAL USES	PILOT PLANTS NOW OPERATING	1980s
PRESSURIZED FLUIDIZED-BED COMBUSTION	APPLICABLE TO LARGER UNITS THAN ATMOSPHERIC VERSION; MORE EFFICIENT, BETTER CONTROL OF N & S OXIDES	13-MWE PILOT PLANT PLANNED	1990s
GASIFICATION COMBINED-CYCLE (STEAM & GAS)	BURN MED-BTU GAS PRODUCED FROM COAL AT GENERATING SITE; REQUIRES HIGH OPERATING TEMPERATURES	DEMONSTRATION PLANT NOW BEING BUILT	1990s
MOLTEN-CARBONATE FUEL CELLS	ESSENTIALLY NOISELESS, POLLUTION-FREE, AND EFFICIENT; COULD USE LOW- OR MED-BTU GAS AS SOURCE OF HYDROGEN IONS FOR FUEL	5 TO 10 YEARS FROM DEMONSTRATION WITH SYNTHETIC GAS FROM COAL	LATE 1990s; LAGS OTHER FUEL CELL DEVELOPMENT BY 5 YEARS
MAGNETOHYDRO-DYNAMICS	POTENTIAL 50% CONVERSION EFFICIENCY FROM COAL TO ELECTRICITY; S CAN BE SEPARATED OUT IN OPERATION; HIGH TEMP. EXHAUST COULD DRIVE TURBINE	PILOT PLANT IN U.S.S.R. FUELED BY NATURAL GAS; COAL SYSTEM STILL EXPERIMENTAL	2000 OR LATER
SYNTHETIC GAS	LOW- & MED-BTU GAS CAN BE MADE NOW, BUT IT IS EXPENSIVE HIGH-BTU GAS (METHANE) ALSO FEASIBLE, BUT EVEN MORE EXPENSIVE	2ND GENERATION TECHNOLOGIES ARE IN PILOT PLANTS, AND 3RD GENERATION IS IN DESIGN STAGE	1990s FOR 2ND GENERATION PROCESSES
SYNTHETIC OIL	INDIRECT LIQUIFACTION TECHNOLOGY IS COMPLICATED, EXPENSIVE AND INEFFICIENT	USED COMMERCIALY IN SOUTH AFRICA	
	PYROLYSIS PRODUCES A RANGE OF PRODUCTS, INCLUDING REFINABLE HEAVY, HIGH-SULFUR OILS & CHAR (FOR WHICH THERE IS NO READY MARKET)	SMALL EXPERIMENTAL UNIT OPERATING SINCE 1971; NOT FAVORED IN CURRENT PROGRAM	1980s
	SOLVENT EXTRACTION AND CATALYTIC HYDROGENATION: EXPENSIVE CATALYSTS, BURDEN OF HAZARDOUS WASTES AND CONTROL OF NITROGEN	PILOT PLANTS NOW TESTING SEVERAL PROCESSES	1990s

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Table 1

PRIME OBJECTIVES OF NATIONAL COAL POLICY - CONAES RECOMMENDATIONS

(Adapted with permission from reference 1, pages 21 & 23)

1. PROVIDE STRONG INVESTMENT INCENTIVES FOR PRIVATE SECTOR TO ESTABLISH A SYNTHETIC FUEL INDUSTRY IN TIME TO COMPENSATE FOR DECLINING DOMESTIC AND IMPORTED OIL SUPPLIES (PROBABLY SOMETIME NEAR 1990).
2. CONTINUE BROAD FEDERAL R&D PROGRAM IN FOSSIL FUEL TECHNOLOGY TO WIDEN THE MARKET FOR COAL BY INCREASING THE EFFICIENCY AND ENVIRONMENTAL CLEANLINESS WITH WHICH IT CAN BE USED.
3. IMPROVE HEALTH IN THE MINES BY STRENGTHENING INDUSTRIAL HYGIENE AND PERFORMING THE NECESSARY EPIDEMIOLOGICAL RESEARCH. THE BLACK LUNG PROBLEM ESPECIALLY SHOULD BE CLARIFIED.
4. DEVOTE THE NECESSARY RESOURCES TO SUPPORTING LONG-TERM EPIDEMIOLOGICAL AND LABORATORY STUDIES OF THE PUBLIC HEALTH CONSEQUENCES OF COAL-DERIVED AIR POLLUTANTS, THUS PUTTING AIR QUALITY REGULATION ON A FIRMER SCIENTIFIC BASIS THAT WILL ALLOW MORE CONFIDENT AND EFFICIENT SETTING OF STANDARDS ON WHICH INDUSTRY CAN DEPEND IN ITS LONG-RANGE PLANNING.
5. DEVELOP A LONG-RANGE PLAN, RECOGNIZING THAT COAL PRESENTS SOME SERIOUS ENVIRONMENTAL AND OCCUPATIONAL HEALTH AND SAFETY PROBLEMS, AND THAT IT DOES NOT RELIEVE THE NATION OF ITS NEED TO DEVELOP TRULY SUSTAINABLE ENERGY SOURCES FOR THE LONG-TERM.

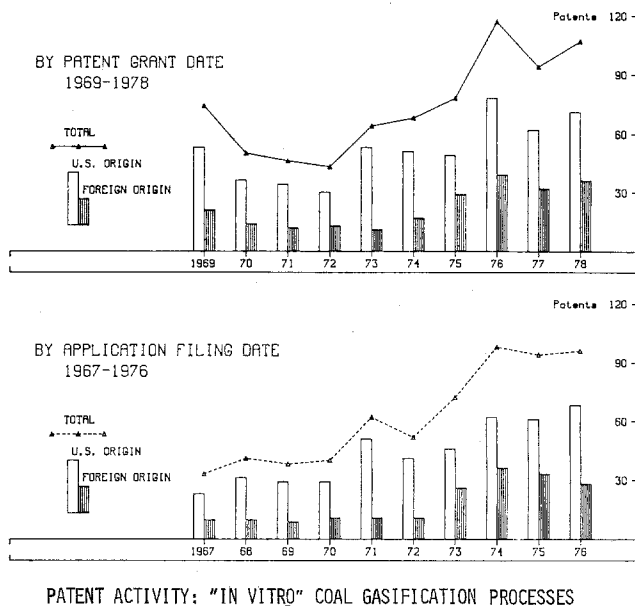
Table 2

ing the synthetic fuel plants in South Africa, says construction of plants necessary to achieve the Synfuel Corporation's goal will require more than 150,000 skilled workers and engineers at peak, and a new plant will need to be started ever two to three months from 1981 through 1986 to reach target capacity by 1992. Such plants would need to average 25 times the size of the largest synthetic fuel plant in the U.S. today, which just went on stream last June. That plant, on the Big Sandy River in Kentucky, will produce 1,800 barrels per day of liquid fuels from 600 tons of coal, and it cost \$200 million. The projected plants will probably cost about \$1.5 billion each. The Syn Fuels Corporation is supposed to foster desirable developments, but only if all other approaches fail will it set up government-owned projects, like the World War II synthetic rubber plants.

time, they expect indefinitely sustainable energy sources to begin to become available. However, in the short term, they see little room to maneuver. Coal has

Domestic Demand

Given "reasonably coherent policy and successful research and development," the NRC estimated that domestic demand for coal will approach a billion tons per year (from 20 to 25 quads) by 1985, at which time some new synthetic fuel and direct combustion technologies will be on the verge of commercialization. By 2010, they expect U.S. coal use to reach two billion tons annually (three times the present level), and another half billion tons may be exported. About that



(From reference 2, Synthetic Fuels, page 135.)

Figure 4

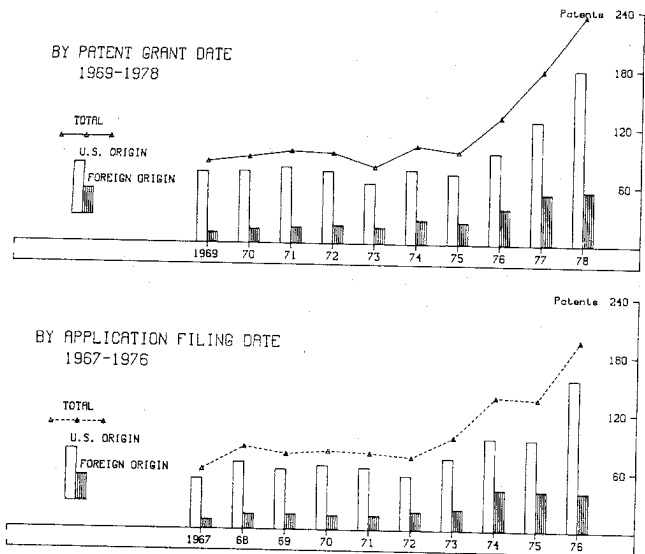


Figure 5

to be used and mainly with current technologies, until at least the turn of the century, regardless of what happens with respect to such alternatives as nuclear fusion or solar energy. Figures 4 and 5 provide an indication of the rate of development of these technologies as reflected in patent activity.

42 Besides the U.S. government subsidized synfuels plants and studies, some enormous private projects are underway such as the shale oil plant in Australia, and the tar sands plant in Canada, that Exxon is building at a cost of \$7 billion each and a \$4 billion coal gasification plant Exxon will build at Troup, Texas. Union Oil has plans for a 50,000-barrel-per-day synfuels plant to be on stream by 1988.

Then, too, there has been a good deal of interest in gasification of coal *in situ*. (Figure 6). The Department of Energy and Gas Research Institute have sup-

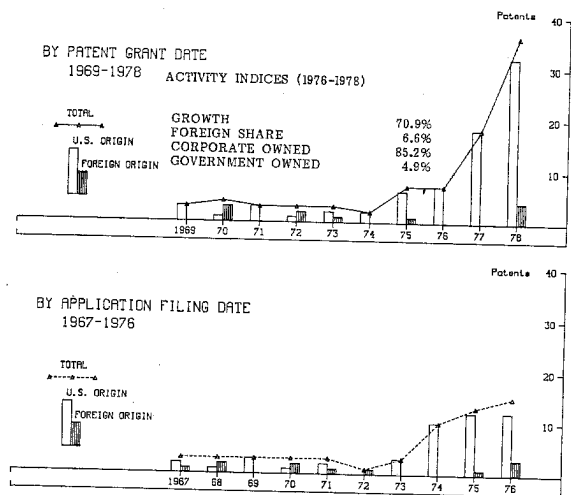
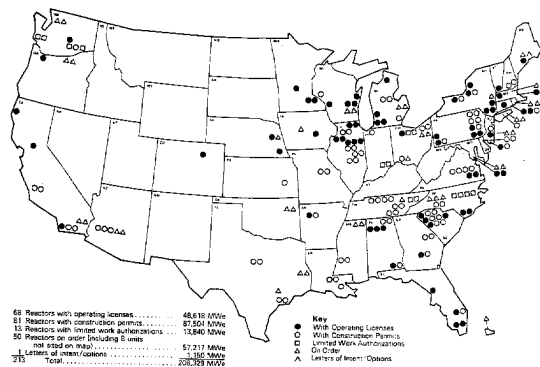


Figure 6



CENTRAL STATION NUCLEAR POWER PLANTS IN THE UNITED STATES, JANUARY 1, 1978
(Reprinted from reference 3, page 41, by courtesy of Marcel Dekker, Inc.)

Figure 7

ported a series of tests, and the most recent results are considered to demonstrate the technical feasibility of developing at least the shallow seams (50-100 feet) of low-grade coal reserves in western states. Gas with a heating value of 200 BTU per cubic foot is produced by injecting steam and oxygen. Economic projections suggest gasoline costs of about \$1 per gallon and substitute natural gas costs of \$4 per million BTU might be realized.

Potential Problem

Potential environmental problems, including subsidence of the earth over the burned coal seam and pollution of ground water, and the fact that underground burns remain quite unpredictable must be weighed against the potential benefits. In particular, water is already scarce in the areas of interest. On a commercial scale, such gasification operations would effectively quadruple the proven reserves of U.S. coal. Experiments are being planned at a "commercially realistic" depth of 600 feet and, if successful, the Lawrence Livermore group conducting the tests thinks commercialization could begin within the next decade. Technical improvements, such as a single well approach, may overcome the earth settling and water pollution that threatens to block the methods of exploitation, based on two or more wells, tested to date.

Nuclear power issues cannot be treated adequately in the time available, but they will demand some of the most critical decisions of the '80s. The light water reactors now in use (Figure 7) utilize only 0.6% of the energy potential of the uranium mined. At most, only 400 to 500 typical 1000 megawatt (about 0.06 quad) reactors of this kind could be supplied from the presently identified resources of uranium. Of course, forecasting the demand for nuclear plants and nuclear fuel has become somewhat difficult in recent years. (Figure 8). The NRC's estimates with respect to a number of nuclear technology developments are summarized in Table 3.

Breeder reactors capable of converting uranium-238 to plutonium-239 could make use of 70% of the energy potential of uranium, and there are conceptual reactors and fuel cycles capable of converting thorium-232 to fissile uranium-233, which could, in principle, make use of 70% of the energy of the thorium that is four times as abundant as uranium in the earth's

DEVELOPMENT STATUS OF NUCLEAR REACTORS AND FUEL CYCLES

(Adapted with permission from reference 1, page 30)

March 1981

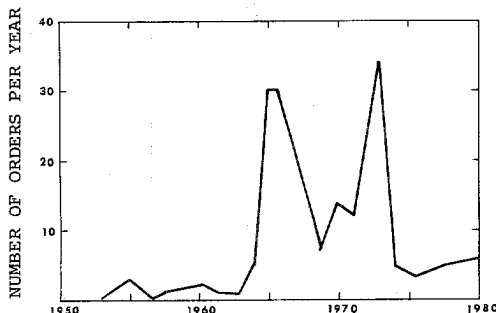
REACTOR TYPE	FUEL CYCLES	DEVELOPMENT STATUS	POSSIBLE COMMERCIAL INTRODUCTION IN U.S.
LIGHT WATER REACTOR	SL. ENRICHED U	COMMERCIAL IN UNITED STATES	1960
SPECTRAL-SHIFT-CONTROL REACTOR	TH-U(W. REPROC.)	CONCEPTUAL DESIGNS & SMALL EXPERIMENT RUN; BORROWS LIGHT WATER REACTOR TECHNOLOGY	1990; TH-U REPROCESSING CYCLE 1995 OR LATER
HEAVY WATER REACTOR	NATURAL U	COMMERCIAL IN CANADA, SOME U.S. EXPERIENCE	1990
HIGH-TEMPERATURE GAS-COOLED REACTOR (HTGR)	TH-U(W. REPROC.)	DEMONSTRATION RUNNING; FUEL CYCLE PARTLY DEVELOPED	1985; TH-U REPROCESSING CYCLE 1995 OR LATER
LIQUID-METAL FAST BREEDER REACTOR (LMFBR)	U-Pu(W.REPROC.)	MANY DEMONSTRATIONS IN U.S. AND ABROAD	1995; SHORT TURNAROUND, HIGH THROUGHPUT & HIGH Pu RECOVERY UNDEMONSTRATED
LIGHT WATER BREEDER	TH-U(W. REPROC.)	EXPERIMENT UNDERWAY	1990; TH-U REPROC. LATER
MOLTEN-SALT BREEDER	TH-U(W. REPROC.)	EXPT.RUN; MUCH DEVELOPMENT NEEDED	2005
GAS-COOLED FAST BREEDER	U-Pu OR TH-U	CONCEPTS ONLY; BORROWS LMFBR AND HTGR TECHNOLOGY	2000

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Table 3

crust. Advanced converters (the reactors shown above the line in Table 3) are intermediate between light water and breeder. For practical purposes, the NRC says, "Fuel costs for breeders would make a negligible contribution to the cost of electricity. Thus, the economics of breeders are closer to those of renewable resources than to those of nonrenewable resources".

During the '70s, Congress continued to fund breeder development despite Administration opposition on international political grounds. The dates in Table 3 presumed firm decisions would be made in 1978 to proceed with commercialization — which, of course, were not made. On the basis of light water reactor experience, it will take about 15 years after introduction to have significant reactor capacity in place.



ORDERS FOR NUCLEAR POWER PLANTS IN U.S.

(Reprinted from ref. 3, by courtesy of Marcel Dekker, Inc.)

Figure 8

The NRC committee could not reach a consensus on whether the likelihood of circumstances favoring one of improvements called advanced converter reactors is great enough to warrant their development as insurance against difficulties and delays in developing the liquid-metal fast-breeder reactor (LMFBR). It did, however, reach general agreement that the LMFBR dominates the nuclear alternatives over the widest range of assumed future circumstances, provided that its cost goals and other technical objectives can be realized. Some argue that the LMFBR would be needed only for growth in electricity demand that could be avoided in this country by "sensible conservation policies".

The advocates of this view believe the U.S.A. should forego the benefits of reprocessing and the breeder to demonstrate how seriously this nation regards the nuclear weapons proliferation problem, treating the LMFBR as a long-term technology of last resort to be used only if research in the coming decades indicates that other long-term options are much more costly or will not be available in time to offset the phasing out of light water reactors. On the other side, it is argued that the commercial nuclear fuel cycle is the least likely and the most expensive of several possible paths to nuclear weapons proliferation.

In any case, the LMFBR is further along in development than any other advanced reactor. Britain, France, West Germany, Japan and the USSR all have their own LMFBR developments under way.

The Clinch River breeder reactor, under construc-

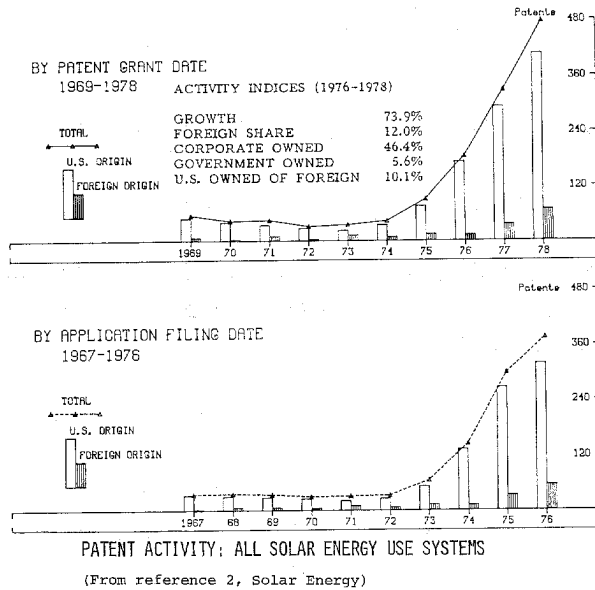


Figure 9

tion, is the 400 megawatt pilot stage between the prototype which has been operated at Idaho Falls for over 15 years and commercial designs on the order of 1,000 megawatts. Construction of a commercial breeder will begin somewhere in the world within 10 years and significant capacity could be in place by the year 2000.

The controversy over the breeder reactor is just one of the many aspects of technology in the '80s to which the following NRC statement applies:

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"Decisions among technological options will have to be reached — if only in the form of postponements of action — before the technical uncertainties can be fully resolved. To a great extent, therefore, technical questions, as well as social and institutional ones, will be decided by political processes".

Nuclear, in the judgment of the NRC committee, is not a technology of the 20th century. There is rising optimism that a demonstration of technical feasibility will be made within the next five years. Until that time, little can be said about the engineer-

ing or economic feasibility of fusion as a source of power. However, the NRC committee anticipates that the capital costs of fusion power plants and delivered energy costs will be higher than those of fission breeder reactors.

The prospects of geothermal energy are not a great deal better. We have in my part of the country the only geothermal electric plant in the United States and the largest (565 megawatt) in the world, which exploits the steam reservoirs, at The Geysers, north of San Francisco. That plant's capacity may be expanded by as much as a factor of 10, to 0.3 quad/year, but the sort of geothermal reservoir at The Geysers is the rarest. It was anticipated by the NRC committee that by 1981 there will be enough information to "permit intelligent decisions on the feasibility of constructing electrical generating plants using geopressurized reservoirs", that, by co-production of hot brine and the natural gas with which it is saturated, might prove to be an economical source of energy. The ballpark estimate of the NRC was that as much as 25,000 megawatts of electrical generating capacity (1.5 quad) might eventually be installed along the Gulf Coast, where the largest known geopressurized reservoirs lie. The technical challenges for exploiting geothermal resources are many and formidable. Even under the most optimistic assumptions, the maximum utilization of geothermal energy in 2010 will be far less than that attainable from fission or solar developments.

Solar Energy

The NRC's opinion is that "in the long term, it should be possible for solar energy to provide each of the energy forms used by people: heat, electricity and fuels. In the near term, outside of hydroelectric power — included by convention with solar energy — only certain heating applications are economical. . . . A major issue for national solar energy policy is the balance of research and development effort among the variety of solar technologies. The federal solar energy program emphasizes technologies for producing electricity, but the most important use of solar energy in the long-term future may, in fact, be the synthesis of fluid fuels, which could solve the problem of energy storage and make good use of the established distribution system developed for gas and oil". (Figures 9-11 illustrate patent activity trends representative of interest in solar energy.)

Methods of domestic space and water heating and production of hot water or low-pressure steam for industrial and agricultural processes are "fairly well developed" and NRC anticipates "widespread commercialization in the intermediate term." Nevertheless, solar heating remains more costly than conventional alternatives in initial investment and BTU for BTU, unless social costs (i.e. limitation of oil importation) are somehow factored in. This is the rationale for the substantial government subsidies being supplied to this sector, which is enabling the industry to get on its feet in the face of otherwise prohibitive economics.

"The amount of electricity that could, in principle, be generated by solar energy could more than provide for present demand. The main obstacle is cost; until

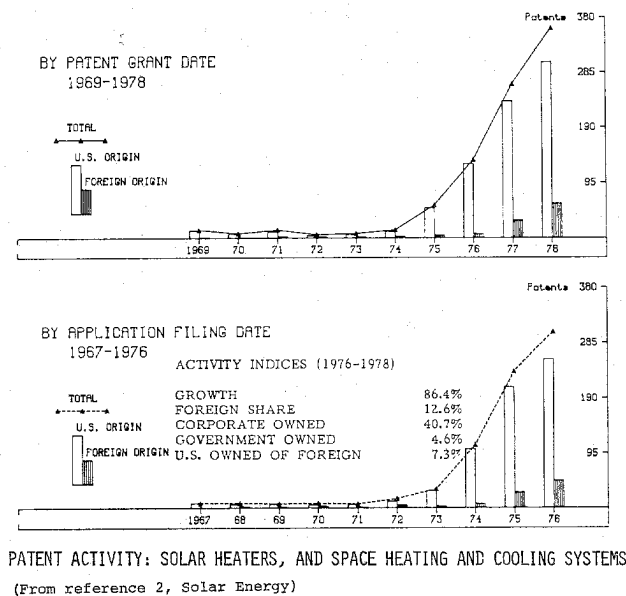
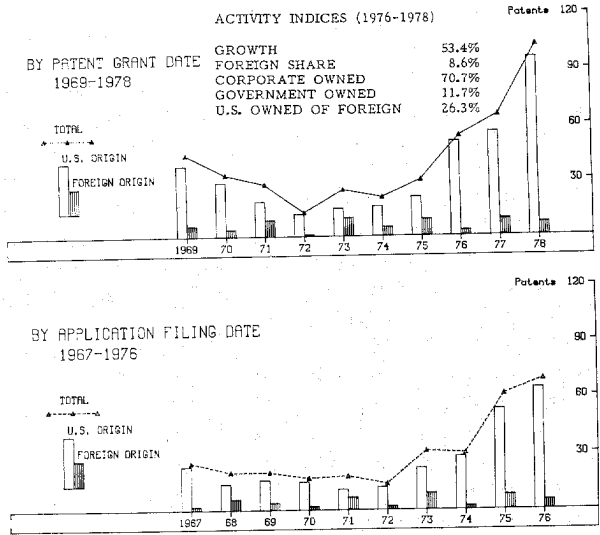


Figure 10



PATENT ACTIVITY: DIRECT CONVERSION OF SOLAR ENERGY TO ELECTRICITY
(From reference 2, Solar Energy)

Figure 11

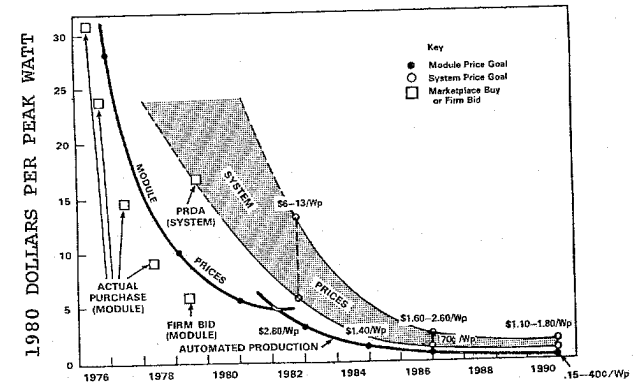
major technical breakthroughs occur, solar electricity will be expensive compared to alternatives." Table 4 categorizes the major technologies for conversion of solar energy to electricity.

Direct or photovoltaic conversion is a commercial technology used in space and remote installations where performance, rather than cost, is the principal concern. Efficiency and reliability have been attained but at costs more than 20 times the prevailing cost of residential electricity. However, the economic outlook for photovoltaics is considerably more favorable than it was a few years ago. A number of technical improvements have occurred recently. The Department of Energy has articulated goals and costs have been declining. (Figure 12).

The National Research Council concluded, "Unlike solar thermal conversion, photovoltaics is a field in which fundamental research could yield dramatic returns . . . Given the high stakes in solar energy and the long-term nature of its political benefits, the present investment in exploratory research for photovoltaics is still inadequate, though recently much improved." As its contribution to a running debate about how the necessary additional cost reductions might be achieved — whether through mass production with present technology and evolutionary improvements or

- GENERATION OF ELECTRIC POWER FROM SOLAR RADIATION
- DIRECT PHOTOVOLTAIC CONVERSION
- SOLAR THERMAL CONVERSION
- WIND AND HYDROPOWER
- OCEAN THERMAL ENERGY CONVERSION
- BIOMASS-DERIVED FUELS
- FUEL CELLS AND WATER SPLITTING

Table 4



Department of Energy Price Goals for Photovoltaic Systems and Modules (From ref. 4, p.8)

Figure 12

through a breakthrough in materials and device configurations resulting from exploratory research — the NRC opts for the "exploratory development approach in preference to the mass production strategy".

Since silicon photovoltaic cells were first invented 25 years ago, they have been made by converting the polycrystalline structure of purified silicon into the orderly structure of a single crystal by the costly, tedious process of growing an ingot around a seed crystal. Then, up to three-quarters of the ingot is destroyed in the process of cutting thin slices with a diamond saw, grinding and polishing the resultant wafers. Alternatives utilizing silicon films, ribbons, and sheets of amorphous (glassy) silicon alloys emerged in the late '70s.

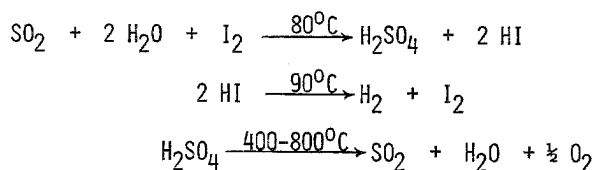
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This past year, the efforts of one pioneer in this area were given the endorsement of a substantial licensing/joint development agreement. Stanford Ovshinsky's 20-year-old development company, Energy Conversion Devices, became a party to, first a \$3 million and then a \$25 million, arrangements with Atlantic Richfield and ARCO Solar to cooperate and cross-license on the development of amorphous photovoltaic devices. All the licenses are nonexclusive and royalty-bearing, and Energy Conversion Devices will receive, in addition to about \$11 million during the past year, another \$17 million in 1981 and '82 to utilize in developing its technology and to build a pilot production facility. Such deals may become common when energy is the subject

Other silicon and non-silicon photovoltaics, such as Boeing's ultra-thin copper indium selenide/cadmium sulfide on low-cost alumina, also look promising. Nevertheless, the NRC and American Physical Society predict that in the year 2000, only one percent of electricity demand is likely to be satisfied by photovoltaics.

The NRC strongly recommends that exploration of many long-term solar options take precedence over concentration on large-scale demonstrations of one or a few, far in advance of their expected deployment. They suggest that premature demonstrations may prove counterproductive, and they are critical of the fact that the solar tower concept has been the most heavily financed system for generating electricity with thermal energy from the sun, although projected costs lie in the range of 5 to 10 times the current cost

Table 5. THE SULFUR - IODINE CYCLE



(See Proceedings of the 3rd World Hydrogen Energy Conference, June, 1980, Tokyo, Pergamon Press, for additional examples of Water-splitting R&D)

Table 5

of electricity, if storage costs are included. This is the type of system in which the rays of the sun are focused on large boilers with large arrays of tracking mirrors (heliostats). While there appears to be little room for technology to reduce the costs of such a steam generator, because the bulk of the cost is steel and concrete, there may be more opportunities for significant innovation in schemes such as thermochemical solar reactors, where steam generation is not the primary solar transformation.

For example, since 1973 the Naval Research Laboratory has been working on a system, referred to as Solchem, in which solar energy is converted to chemical energy in a closed loop system. The relatively low-temperature but high energy-content gases from many such reactors would be transported to a central facility where, in the presence of a suitable catalyst, the working gas would give up as heat the chemical energy absorbed in the solar furnaces. It is proposed that the heat be entrapped as latent heat-of-fusion in a mass of eutectic salt. The eutectic salt, which could be used to store heat from other sources too, reduces the volume required for storage 50-fold from what would be necessary to store the working gas itself.

Solar production of hydrogen by water splitting is being approached from two directions. One, not far removed from the concept just described, involves thermochemical reactions which accomplish the separation of hydrogen and oxygen in a series of reactions that recycle the other reactants. (Direct water splitting requires temperatures of about 5000° to achieve significant equilibrium yields of hydrogen.)

One cycle (based on the reactions outlined in Table 5) has been under investigation by General Atomic Company for several years. Projected efficiency of the cycle is 47%, which is somewhat better than that for hydrogen production by electrolysis (37%). The high temperature sulfuric acid decomposition would need to be run during the daylight hours when there is intense sunlight available. The other chemical cycle reactions, distillations, and power generation could be run with the heat from a low temperature mirror field coupled to a molten salt heat storage system on a 24-hour basis.

Alternative approaches to water splitting attempt to emulate photosynthesis. In either case, the product is hydrogen, which can also be generated from fossil fuels. The hydrogen could be used as a fuel, which would not generate carbon dioxide, either in conventional combustion or fuel cells, or it could be used for chemical synthesis. Concepts have been put forth for autos fueled by hydrogen, stored as solid hydrides, and most recently for a hydrogen aircraft.

A proposal is currently being circulated to governments and companies to initiate a three-year first phase of an R&D program, the second phase of which would include flying experimental hydrogen-powered aircraft on international cargo routes. Only minor modifications of engines and aircraft (a 40-foot stretched L-1011) would be necessary, according to my friends at Lockheed. A study on the relative crash/fire hazards of a hydrogen aircraft is already under way, and the airline could be operational by 1987 if Phase I funding were authorized soon.

Aerospace brings together many high-technology fields. Our space shuttle should be operational long before hydrogen aircraft. Many regard its development as the beginning of the industrialization of extraterrestrial space. However, industrialization of space seems likely to move slowly unless priorities shift substantially. As important as the massive shuttle hardware are the microscopic developments in electronics, communications and information processing, which are sure to have widespread effects in the '80s on earth-bound activities.

Relentless miniaturization and integration of hardware and software will be hallmarks of electronics in the next decade. Integrated circuits (ICs), especially the very large-scale varieties, developed in the '70s will make their real impact in the '80s. Within the next few years, virtually any device that can be improved by storing and processing of information will have microprocessor capacity built into it. The social and psychological consequences are among the few things that remain incalculable.

Smaller has meant faster and cheaper since these applications of solid-state physics began in the 1950s, although the investments in design, development and capital costs have been skyrocketing. Time and again, after a period in which design and development costs were paid off and yields improved substantially, each successive generation of ICs settles down to about the same price as its predecessor, which had half as many transistors. It's just 20 years since the first ICs were made, and now they are up to 70,000 component microcomputers with 64 kilobit memory — the result of chip density being doubled every year and a half. If the rate of doubling continues, there will be 10 million bit IC chips by the end of the decade. Magnetic bubble memories with one million bit capacity are already possible and 100 million bit memory chips may soon displace those charmingly-named "floppy discs" and their associated mechanical devices.

The capital equipment necessary to stay abreast of the technology brought consolidation to an industry renowned for its entrepreneurial character. The development and production of chips is now strictly big business. Gordon Moore, of Intel, recently forecast that worldwide sales of microelectronics components will soar from \$11 billion in '79 to \$100 billion in 1990. Overall electronics — including computers, telecommunications devices, consumer products like pocket calculators and games, industrial process control equipment, scientific instruments, and defense systems — will become a \$400 billion industry by the late 1980s, a figure that puts electronics in the same league with oil, automobiles, and other giants. By the mid-1980s, Norman Zimbel, of A. D. Little, predicts

the computer systems field will be down to a handful of major competitors. However, at the moment there are an even dozen producers of 64K random access memory chips lined up at the start of one of the hottest competitions since the Homesteader's Act, and this time the Japanese are in the race! The price of this new generation 64K chip is projected to drop from about \$100 in 1980 to near \$10 by 1983. You can imagine the volume they anticipate.

The technological implications of microcomputing only begin with the industry that produces the chips. From sensors to robotic implementors, computing capabilities will stimulate innovation incredibly. The sources of the semi-conductors and some of their clients will be giants, but the opportunities for little guys, in software and hardware for specific applications, will be limited only by imagination and the general economy.

Lasers

Solid-state lasers and fiber optics represent the new wave in communications. Image and speech recognition and synthesis interfaces, coupled with modern memory capacity and microprocessors, promise to make the electronic office a near-term reality. White-collar work provides the ripest opportunities; while the American factory worker's productivity increased 84% in the past decade, the office worker's output inched ahead only 0.4%, and we now constitute the majority (51%) of the workforce.

Transportation through the '80s may not be much different from what it is today. Perhaps some of us will have one of the new town-mobiles propelled by electricity, but we'd be in a small minority, most forecasters think. All the new G.M. cars have on-board computers and that's just the beginning of the use of electronics to prop up the internal combustion engine, conserving fuel and controlling emissions, as well as assisting in the diagnosis of malfunctions. The French National Railways will be running the world's fastest train in 1981 — covering the 266 miles between Paris and Lyons in two hours — as the Europeans and Japanese continue to outpace the U.S.A. in non-airborne mass transit.

We all sense that the '80s will see an inordinate emphasis laid on technology for defense (and offense, for that matter). There's the MX and the cruise missiles and replacement of our strategic bombers from the 1950s. We see articles on laser weapon systems, particle beams, and invisible aircraft, and we know an enormous technological effort is gathering strength, but I can't bring myself to spend much time on that sort of thing.

On the subject of government involvement, *Business Week* reported recently that 80% of the Air Force's computer budget is spent on software and the Government Accounting Office found that annual government expenditures on software now exceed \$6 billion. In fact, software development is identified as a new frontier for technology in the '80s, for it represents the labor-intensive bottleneck of computerization. Among other incentives, the fact that the Japanese government has launched a \$100 million effort on software development should stimulate U.S. firms to

strive to maintain their present significant lead in programming, which is the basis of U.S. leadership in the computer industry.

But more than one-half of the industrial robots in the world are being used in Japanese plants, and they install more robots each year than the total in U.S. factories. This may account for some of the Japanese commercial success, although they apparently aren't exporting robots. Marketing of robots is being considered by U.S. computer firms, some of which have developed sophisticated assembly robots, like the 24 robots equipped with camera "eyes" that Texas Instruments has in its own plants. A real boom in robotics is forecast for the '80s, with General Electric and Westinghouse showing the way by automating major plants of their own. For example, G.E. is spending \$5.1 million this year for 47 new robots, which it expects will save \$2.6 million yearly in labor and materials. Labor/management conflict seems an inevitable outcome of this new trend. Vision is generally considered the key to the next generation of robots, and workers in the field fear that Japan now has a three-year lead in vision systems.

The Ministry of International Trade and Industry is sponsoring a Japanese drive to set up an unmanned manufacturing facility by 1985. Europeans are strong in robotics, too; Fiat officials told *Business Week* they think 90% of the workforce could be eliminated from an automobile factory by 1990. Renault has a robot with a television-camera "eye" that can identify each of 200 parts presented to it at random on a conveyor, then reach out and grasp each part at the proper spot for whatever the next operation may be.

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Biology

I shall turn, finally, to the realm of biology, which happens to be the area with which I'm most familiar. We are witnessing what should be recorded as the Golden Age of biology. A century after a candle was lit by Darwin, our contemporary scene is illuminated by a bank of floodlights that are revealing the mechanisms of evolution and development in molecular terms. Entrepreneurs have been taking advantage of the light and using licensing, along with venture capital, as tools to dig for treasure.

Pure science, such as the elucidation of the double helix structure of DNA, made it possible to comprehend the biochemistry of an organism such as the bacterium, *E. Coli*. Late in the '70s, techniques were devised to open natural genetic molecules, called plasmids, and insert fragments of DNA from various sources; then reseal the circular plasmid and return it to a bacterium, where it reproduces as the bacteria multiply, and where the characteristic represented by the inserted DNA can be expressed. It is practically impossible to convey the sophistication of this still young art, but I don't want to leave you with the impression they just stick in some DNA and the bug makes a protein. The scientific data and methodology base make it possible to manipulate the nucleotide sequences that serve as punctuation and signals, which are involved in the process of translating DNA to RNA to proteins, such as enzymes and hormones. In large part, this is the result of enzymatic techniques

that make it easy to determine the precise sequence of long segments of DNA. This approach will enable the modification, not only of microorganisms, but of animals and plants, even humans, if we wish it. The potential and implications are staggering.

Closely related to developments in genetics are the revolutionary things occurring in immunology. An example is the preparation of a novel cell for the purpose of producing abundant pure antibody. A white blood cell that produces a desirable antibody can now be fused with a tumor cell, called a myeloma, that has the desirable property of proliferating indefinitely, unlike the short-lived white blood cell. The hybrid product is identified and selected by the combination of properties conferred on it by the parents; then a clone colony descended from a single cell is grown from that hybridoma. An antibody derived from a hybridoma clone is about as specific a chemical reagent as can be imagined, and their affinity for their unique targets enables the finding of "needles" in chemical "haystacks." That is a dream come true. In less than five years these monoclonal antibodies have become exquisitely sensitive tools used throughout biological research, and they seem destined for many diagnostic and some therapeutic purposes in the '80s. Some anticipate increasing use of antibodies to effect chemical separations and purification on a large scale.

Application Areas

48 Recombinant DNA and monoclonal antibody developments are but two of the burgeoning application areas encompassed by the term "biotechnology", upon the basis of which many predict an "age" comparable to the recent eras in which we have seen the ascendancy of electronics of synthetic chemicals. In the context of economics revised by soaring oil prices, possible applications of contemporary insights into molecular biology appear far more attractive than they would have been previously. The priorities of the '80s will have a profound influence on the speed and depth with which biotechnologies pervade fields outside the realm of medicine. Speculation is rife, for example, about the impact of molecular biology on agriculture — with concepts for crop improvement, such as nitrogen-fixing plants, straining the state of knowledge of

plant physiology and genetics. No doubt, the next decade will be a booming period for applications-oriented biological research. Perceptible consequences in the economy within the timeframe of a decade will be more limited than the current hyperbole and Wall Street interest suggests.

Inevitably, this is an incomplete overview of the techno-scape, but even such a brief synopsis would be less authoritative were it not for the existence of some recent book-length surveys that we recommend for further reading, in preparation for the decade ahead. On the paramount subject of energy, in addition to the comprehensive report of the Committee on Nuclear and Alternative Energy Systems (CONAES) of the National Research Council (which we have referred to as the NRC report)¹, a Harvard Business School Energy Project put together a very readable analysis and recommendations⁵. A broader, but still limited perspective of science and technology, through 1985, was prepared by another NRC committee chaired by R. E. Gomory of IBM for the National Science Foundation⁶. Much lighter reading and generously illustrated is a Print Project paperback ostensibly directed to the technologically illiterate⁷. I think many in this audience would find this "Techno/peasant Manual" stimulating and worthwhile, although it should not be depended upon for facts. Finally, Toffler's *Third Wave*⁸ has furnished a synthesis of the thrusts of contemporary society which facilitate my personal consideration of the implications of technological and other developments, but the choice of such a sweeping viewpoint must be an entirely personal one.

NOTES:

1. *Energy in Transition: 1985-2010*, H. Brooks and E. L. Ginzton, eds. W. H. Freeman & Co., San Francisco, 1980.
2. *Technology Assessment & Forecast and Patent Profiles* series, published by the Patent and Trademark Office.
3. *Nuclear Power*, J. J. Duderstadt, Marcel Dekker, Inc., N.Y., 1979.
4. "Overview — Cost Goals in the LSA Project", P. D. Maycock (DOE), Photovoltaic Conference, 1980.
5. *Energy Future*, R. Stobaugh and D. Yergin, eds., Random House, N.Y., 1979.
6. *Science and Technology: A Five Year Outlook*, National Science Foundation, W. H. Freeman & Co., San Francisco, 1979.
7. *The Techno/peasant Survival Manual*, C. Dowling, et al., Bantam Books, Inc., N.Y., 1980.
8. *The Third Wave*, A. Toffler, William Morrow and Co., Inc., N.Y. 1980.