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New and Renewable Energy in the United States of America

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Preface

This report is a contribution of the United States of America to preparations for the 1981 United Nations Conference on New and Renewable Sources of Energy. It describes the current technical and economic status of technologies and U.S. experience with and expectations for new and renewable energy sources in the United States. It also outlines the roles of the public and private sectors in developing and using these energy sources.

Additional reports are being prepared as further contributions to the work of the Conference. One of these describes the U.S. international programs that relate to the production or use of energy from new or renewable sources. Another describes the development of these technologies and systems in the United States and the sources of information about them.

This report includes a short bibliography and suggestions for obtaining additional information. The glossary and a list of acronyms should assist the reader in understanding the special terms used by the developers and users of these technologies.

The report was prepared by the Solar Energy Research Institute, with funding and guidance from the Department of Energy and advice from an Interagency Task Force led by the Department of State. Inquiries about its contents should be addressed to the UNCNRSE Project Coordinator, Solar Energy Research Institute, 1617 Cole Boulevard, Golden, Colorado 80401.

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Chapter 1
Overview

New and Renewable Energy: Past, Present, and Future

Like other countries, the United States depended almost entirely on renewable energy resources until little more than a century ago. The early American immigrants relied, as had the native inhabitants, on wood for home cooking and heating; in fact, as late as 1850 wood met close to 90 percent of U.S. energy needs. They also used hydropower to drive their grain and industrial mills, and harnessed the wind to drive mills, water pumps, and sailing ships. Biomass, especially in the form of feed for draft animals, was for hundreds of years the principal power source for agriculture.

As fossil fuels were developed and as the steam engine and then the internal combustion engine became commonplace, reliance on renewable resources faded. Coal, which provided only 10 percent of U.S. commercial energy in 1850, came to dominate the market, supplying more than 75 percent by the early 1900s. In ensuing decades, coal was itself replaced by oil, which today meets close to half of U.S. energy needs. Natural gas, which supplied less than 5 percent of U.S. energy in 1920, now accounts for about 25 percent.

With domestic and world supplies inexpensive and abundant, fossil fuels have powered more than a century of industrialization, agricultural progress, and economic growth in the United States, as well as in many other countries.

Domestic production of oil and natural gas climbed steadily until the early 1970s. During the 1960s and especially the 1970s, the expansion of the U.S. economy and the leveling off of domestic oil production led to increased imports of foreign oil. By 1978 more than 40 percent of total U.S. oil demand was being met by imports. The decline in U.S. oil production in the 1970s, and the economic burdens and vulnerability associated with importing growing amounts of oil and gas, have spurred the United States' search for energy resource alternatives. While the major contribution in the near term will be made by conventional energy sources, increased efficiency, and other conservation measures, the United States has also undertaken a large-scale effort to develop new and renewable energy sources. Being put to the test are experimental technologies for extracting the enormous amount of oil trapped in shale rock and in tar sands.

Other technologies permit the retrieval of more oil and gas than can be extracted with conventional methods. Since coal is so plentiful in the United States, another prospect is the conversion of coal into so-called synthetic oil and gas. At the same time, policy makers and researchers are looking for ways to increase public acceptance and use of nuclear fission and breeder reactor power plants and to establish the technical feasibility of nuclear fusion. Geothermal resources are also being assessed and exploited.

Energy plantations will require large-scale power equipment for rapidly harvesting trees. These devices may resemble this whole-log-chipper, which facilitates the transfer of the wood from the field to the end-use location.

In addition to these U.S. commitments to new energy sources, major research efforts are continuing on renewable energy resources, which are continuously replenished by the energy in sunlight. Wind, biomass, ocean, and direct solar radiation are being studied. They lend themselves well to meeting smaller, more dispersed energy needs, generally have relatively fewer environmental impacts than conventional alternatives (by not requiring a continuous supply of purchased fuel), and are inflation-resistant to a large extent.

Currently, renewable energy sources meet more than 5 percent of U.S. energy needs. Most of this fraction—more than 3 percent of U.S. energy consumption—is supplied by hydropower. The second major renewable resource in present use is wood, which now provides about 2 percent of the national energy supply. Wood's increasing share of the energy budget reflects Americans' growing reliance on wood-burning heaters in homes, and industry's use of wood residues in the boilers of pulp and paper factories and other wood-related operations.

The use of other renewable energy sources is rising but presently accounts for only a small fraction of national energy consumption. In several cases, changing economics and circumstances are causing a return to long-abandoned energy sources with new or improved technologies. For example, windpower—so popular in previous periods but nearly abandoned half a century ago—is beginning to be harnessed again for water pumping and electricity generation. Early in this century, tens of thousands of U.S. homes had solar water heaters, supplied by many small U.S. companies, that disappeared as more convenient and inex-

pensive electric and gas-fired water heaters became widely available. Today, a new solar water-heating industry is rapidly emerging. The energy-efficient design of buildings nearly became a lost art; now, passive solar design is being taught in architectural schools and applied by many builders. Alcohol-fuel supplements were used in early combustion engines but then fell into disuse; now, consumption of gasohol (a gasoline-alcohol mixture) is increasing rapidly.

The technical feasibility of a number of new technologies has been proven, but most of the systems based on these technologies have not yet become sufficiently competitive in the United States to warrant widespread use. For example, photovoltaic cells—which convert sunlight directly to electricity—provide critical energy for satellites in the U.S. space program, but they remain too expensive for most common electricity uses. As the price of power from the various new and renewable energy systems can be reduced through research and industrial development, these systems can be expected to play growing roles in satisfying U.S. energy needs.

Though some of these technologies have been used for a long time, recent advances reflect progress in thermodynamics and system design, developments in materials and manufacturing processes, and improvements in performance. In particular, some materials used to improve operating efficiency and cut manufacturing costs in solar collectors were little known just a few decades ago. Renewable energy may be humanity's most ancient power source, but it is also becoming the basis for some of our most modern power systems.

Given the many unpredictable factors that influence energy resource use, a precise forecast of the future contributions of new and renewable sources is not possible. But it is certain that the energy future of the United States—and that of the world—cannot be an extension of the recent past. A host of alternative energy sources must be exploited, and the efficiency with which we use energy must increase substantially. Based on what is known about price trends, technology development, private-sector research, and government policies, it is clear that new and renewable forms of energy will increasingly influence the lives of all Americans over the coming decades. Indeed, in the year 2000, we could find

. . . the morning's chill being broken in millions of homes by heat captured from sunlight the day before. Many people showering with water heated the day before by rooftop collectors; others drawing hot water from a community geothermal system or a community solar system that stores sun-heated water for months at a time.

. . . families boiling water for their morning coffee with electricity from batteries charged by rooftop solar cells, or from a utility that generates some of its power from renewable sources—perhaps a combination of hydro, wind, solar thermal, biomass, geothermal, or ocean thermal energy. With appliances much more efficient than they were in 1981, household electricity needs are substantially lower.

. . . people commuting in public transportation powered by solar-charged batteries and others driving to work in cars running on alcohol derived from biomass. Some vehicles are powered by oil from shale or tar sands.

. . . some industries deriving more than half their high-temperature process heat from solar concentrator systems, even as these same systems simultaneously generate a portion of the plants' electricity needs. Other

industries may use geothermal energy or burn biomass for process heat and obtain much of their electricity from wind generators and solar cells. Nearby farms are essentially self-sufficient in energy, producing liquid fuels and natural gas from crop residues and livestock wastes, and electricity from wind or small hydro plants. On windy days, farms may sell the excess wind-generated electricity to the utility (earning credit for days when power from the utility grid is required).

While visionary, this portrait nevertheless is consistent with the energy resource trends in the United States. By the end of this century, the contributions of new and renewable energy to daily life in the United States can be substantial and pervasive.

A National Commitment

Until recently, research activities on new and renewable energy sources were small. In 1970, the Federal Government funded only a few hundred thousand dollars annually for research in these areas. One decade later, annual Federal outlays supporting research were in the hundreds of millions of dollars. Moreover, thousands of companies, citizens' groups, and individuals are experimenting with, installing, buying, servicing, and selling energy systems based upon new and renewable energy resources.

In the mid-1970s, public and governmental interest in new and renewable sources of energy was accelerated by the rapid rise in oil prices and by supply problems. The overall U.S. energy program has been based on both executive and legislative inputs. In terms of executive agencies, the U.S. Department of Energy has the lead responsibility in research on new and renewable energy sources.

Throughout the 1970s, public interest in new and renewable energy mounted. This interest was accelerated in late 1972 by an in-depth study and favorable report from a panel of renewable energy experts convened by the National Science Foundation and the National Aeronautics and Space Administration. The panel's report pointed out the technical feasibility and large potential of solar energy systems to help meet future U.S. needs for energy. This rise in interest had many other roots as well—among them the desire to reduce the economic and security risks associated with escalating dependence on imported oil, and concerns about the possible environmental and social effects of accelerated development of coal and nuclear power. The perception that decentralized renewable technologies could help communities become more self-reliant has appealed to a large number of local organizations. On May 3, 1978—"Sun Day"—millions of Americans proclaimed their support for promoting renewable energy use.

As a result of national enthusiasm for renewable energy resources coming out of the "Sun Day" activities, a top-level study group, The Domestic Policy Review of Solar Energy (the DPR for short), was formed in 1978 to evaluate the potential for the accelerated use of solar-based energy sources. The final report of this group concluded that "significant potential exists for expanding the nation's use of solar energy" and that "many solar technologies are already economic and can be used in a wide range of applications." With concerted efforts to overcome the many barriers to implementing renewable technologies, the report further states, the United States could cost-effectively obtain as much as 20 percent of its energy supply from renewable sources by the year 2000.

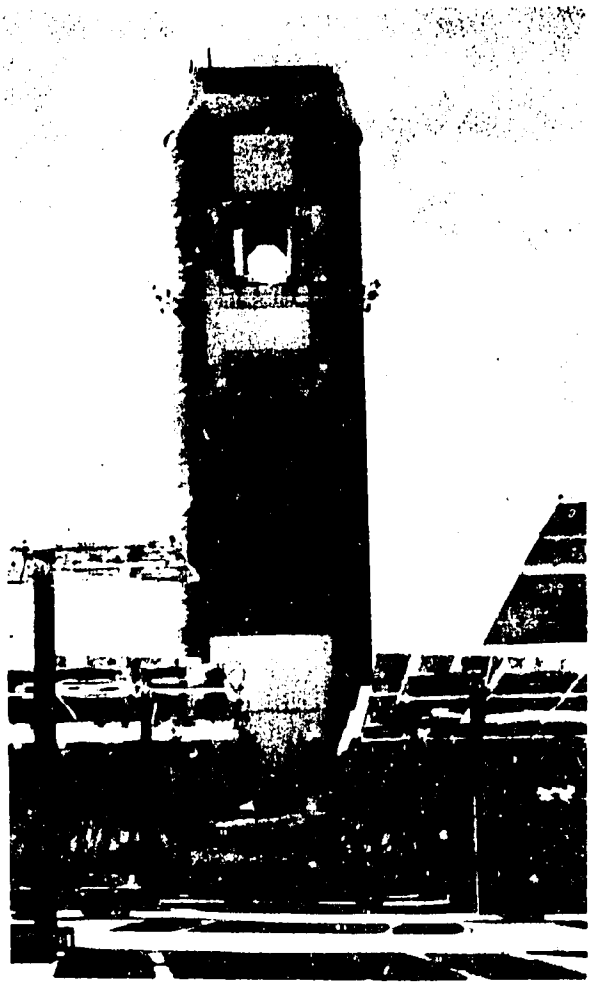
Although progress in the use of renewable energy will be influenced by unpredictable factors, it is possible in general terms to outline a role for renewables. The relative

contribution of hydropower to electricity supplies is expected to increase moderately over the next two decades because the best and largest U.S. resources have already been developed. During this period biomass-based power systems are expected to overtake hydropower as the major renewable energy source. The principal contributions are expected to be the direct combustion of organic matter to produce heat, and the conversion of biomass into alcohol fuel, methane gas, and hydrocarbon-based chemical feedstocks. Biomass-based energy will also be used by electric utilities and residences.

Solar thermal technologies—both the low-temperature systems most commonly used to heat water or buildings and the intermediate- and high-temperature systems used to provide steam for industrial use or electricity generation—are expected to provide small but growing shares of energy for the residential, industrial, and utility sectors by the year 2000. By that time, windpower, photovoltaic cells, and ocean thermal systems are also expected to contribute notably to utility electrical output, and a portion of the electricity production from each will come from small, independent systems.

In 1980, following the second major round of global oil-price rises, the U.S. Congress established targets for the production of synthetic fuels, among them oil from shale and tar sands as well as liquid fuels and gas from coal and biomass. By the early 1990s, the United States hopes to be producing at least two million barrels a day of synthetic fuels, with oil shale and tar sands accounting for perhaps half that amount.*

*Two million barrels a day is equivalent to more than four "quads" per year of energy. One quad is 10^{15} Btu and almost the same as one exajoule or 10^{18} joules. (For perspective, see the glossary.)



The Central Receiver Test Facility has been operating in Albuquerque, New Mexico, under the auspices of the Sandia National Laboratory since October 1978. The facility is capable of delivering a total of over 5 megawatts of thermal energy to one of four test bays inside the 60-meter central tower. Each of the 222 heliostats, or tracking mirrors, is approximately 40 square meters in area. A computer controls the operation of this experimental facility, which is being used to test both heliostat equipment and receiver components.

Private and Governmental Roles

The United States relies mainly on private industry for the development of technologies and for the production and delivery of energy, though industry is sometimes aided by the government when the normal workings of the marketplace do not adequately

serve national security, social, economic, or environmental objectives. In the case of new and renewable energy, both the public and the Federal Government have come to recognize the compelling national interest in hastening the commercial availability of alternative energy sources. Impediments to the employment of new and renewable energy have been identified, and ways are being sought to help overcome them. The major barriers are: high initial cost; limited public awareness of and information about economically competitive technologies; early stages of technology development; and counterproductive Federal, state, and local government regulations and utility policies. Domestic price controls and tax incentives to stimulate oil and gas production have also been a major factor in keeping new and renewable energy sources from competing effectively in the marketplace, although this problem is less severe now than in the past.

To overcome these barriers, the U.S. Government uses four principal tools: research and development; financial incentives; regulatory functions; and information dissemination. Commercialization of new technologies is properly the role of private industry. Federally funded research and development is concentrated on long-term, high-risk, and potentially high-benefit efforts. Presently the Federal Government is decreasing the regulatory controls it has over the economy—it has ended price controls on oil and is considering doing the same for natural gas.

Short-term financial incentives, especially tax credits, have increased in recent years and have greatly accelerated the commercialization of new and renewable energy technologies. These financial inducements indicate that new and renewable technologies are considered ready for practical use.

Perhaps the most significant financial incentive is the Federal income tax credit of 40 percent (up to a total credit of $4,000) for individual homeowners who install renewable energy devices. For example, a homeowner who spends $2000 on a solar hot water heater will pay $800 less Federal income taxes that year. Other important financial incentives include grants for experiments and demonstrations, loan subsidies for energy improvements in housing, and loan guarantees for companies investing in geothermal energy, ocean thermal energy, and synfuels systems.

Several Federal agencies are involved in accelerating the adoption of new and renewable energy. The major agency supporting research, development, demonstration, and information dissemination is the Department of Energy. A portion of its research funding goes to the Solar Energy Research Institute and to various national laboratories. (Most federally sponsored energy research is actually carried out by private firms and universities under contract.) The Department of Housing and Urban Development is involved in promoting the use of renewable energy systems and conservation in housing. To mitigate potential environmental problems by integrating environmental planning into all energy resource development, the Environmental Protection Agency has a program assessing the impacts of all energy systems. The National Aeronautics and Space Administration supports the Department of Energy in research and development of many technologies (especially wind and photovoltaics). The Department of Agriculture has a major responsibility for research and development concerned with biomass-based energy, especially alcohol fuels, and for solar energy systems for farm and rural uses. The Department of Commerce encourages the establishment of renewable energy industries. Besides these Federal departments, a quasi-governmental Synthetic Fuels Corporation has been established by Congress to provide loan guarantees and other subsidies for synfuels (including oil from shale and tar sands and liquid fuels from biomass). Many other Federal agencies are directly and indirectly contributing to the national effort to

This Vermont home is expected to receive 50 percent of its heating and hot water needs from the 16 active solar heating units.

develop new and renewable energy technologies.

The Department of Energy actively participates in international cooperative research, development, and demonstration programs. It has bilateral cooperative agreements in new and renewable energy technologies with a number countries and is involved in many multilateral cooperative programs [most under the umbrella of an International Energy Agency (IEA) agreement]. In addition, Federal laboratories are providing technical support to the Agency for International Development (AID) for various projects in developing countries.

Complementing federally sponsored efforts are state and local government activities aimed at promoting the use of renewable energy at the community level. About half of the fifty states provide homeowners and renters with some additional financial incentives for the purchase of solar water or space-heating systems. These incentives, together with the Federal tax credit, offer a strong inducement to potential buyers. Some cities also provide special incentives for the installation of solar devices in economically depressed inner-city zones.

Many of the states have implemented strong incentives for the use of renewable energy systems. In 1977, California established a state tax credit of 55 percent for solar investments (less for those who also claim the Federal tax credit). California now accounts for nearly half the country's sales of solar hot water heaters. Arizona has recently implemented a state tax credit of 35 percent, which can be added to the Federal tax credit. Many states have enacted laws to provide special incentives—e.g., exemptions from real estate or sales taxes—and to protect landowners' access to sunlight. The latter law prohibits

This Denver, Colorado, home, through a combination of conservation and passive solar energy features, has a total energy consumption approximately 30 percent as large as other new homes nearby. The conventional heating unit is rarely called upon and the backup wood stove has not yet used a cord of wood in the first two heating seasons. The additional cost of the passive features was approximately five percent of the value of the new home.

obstructions that would block sunlight from reaching existing solar systems.

Most industry efforts to develop new and renewable energy technologies have been independent of government funding. At present, industry's financial commitment to research and development on new and renewable energy technologies is comparable to the Federal Government's. Nevertheless, indirect governmental support—such as tax credits, loans, and market-development activities—has helped hundreds of companies begin manufacturing and distributing solar heating systems, wood-burning stoves, wind generators, and other small-scale renewable energy technologies. Thousands of other companies are involved in the sale, construction, and maintenance of new and renewable energy systems. Annual sales of solar collectors now amount to several hundred million dollars. Industries that use and refine biomass (including wood and gasohol) provide energy worth several billion dollars annually. Construction of hydropower (especially small or mini-hydro) facilities is increasing rapidly. U.S. sales of photovoltaic modules and systems are now more than $50 million annually.

In the United States, industry's and government's solar development programs are complemented by the activities of many individuals, community groups, and nonprofit organizations. As one indication, the U.S. Section of the International Solar Energy Society boasted more than 5,500 members in 1980, compared to a few hundred in 1970. The Solar Lobby, a citizens' organization that works to marshall support for renewable energy, has about 35,000 dues-paying members. These and other private groups help disseminate information about renewable energy and

familiarize people with solar technologies. On a typical weekend, an organization in Vermont might be sponsoring a workshop for people interested in building their own solar water heaters. Another in Wyoming might be holding a fair to demonstrate wind and solar devices in operation. At the same time, a group in Washington, D.C., might be conducting a symposium on the potential of biomass fuels.

In the final analysis, the interest and activity of U.S. citizens provide the foundation for the progress the United States expects to make in new and renewable energy development and use.

Renewable Energy Technologies — A Summary

This paper describes ten new and renewable energy technologies in the United States: their technical characteristics, applications and status, economics, barriers and impacts, as well as private and government activities enhancing their development and use. The highlights of the chapters that follow are summarized briefly below.

"Passive solar" refers to the use of building design, along with the minimal use of fans and pumps, to collect and control solar energy. In some cases, passive design and conservation can supply all of a building's heating and cooling needs; more typically, energy needs are reduced to one-third or even to one-fifth of those of conventional buildings. Much of this gain can be achieved at low cost. Yet, greenhouses and most other passive approaches sometimes entail an additional first-cost expense (for added glazing, storage mass, and movable insulation) that must be offset in the initial years of operation. The use of passive solar designs, especially for new single-family residences, has been growing rapidly as increasing numbers of architects and builders become familiar with the techniques. By the year 2000, about half of all new U.S. buildings are expected to have some passive solar design features.

"Active solar" generally involves thermal energy collectors external to the building and pumps (or fans) to move heat-transfer liquids or air through pipes or air ducts into the buildings. Active solar systems are widely used in many countries including the United States for heating water for residential needs, often designated as domestic water heating. These systems are also employed to heat buildings, especially older ones for which passive techniques are impractical. The active system generally uses modular panels, each panel typically covering one or two square meters. One square meter will provide the energy equivalent of up to approximately 100 liters of oil each year in hot water applications, making them economically attractive today when the alternative energy source is electricity or oil. The Federal tax credit of 40 percent has encouraged annual sales of millions of square meters of collectors. However, these annual sales would have to increase by almost one hundred-fold if active solar technologies were to meet approximately 2 percent of all U.S. energy needs by the year 2000.

Intermediate- and high-temperature solar collector systems, which concentrate the sun's rays, can achieve higher temperatures than other thermal energy technologies—renewable or non-renewable. A number of tracking solar collector systems have been developed to follow the sun as the earth rotates. Tracking collectors make it possible to meet many needs for higher-temperature heat—including that for steam, industrial process heat, and electricity generation. Tests of many different concentrators are under way. Intermediate-temperature, line-focusing systems will soon be commercially cost-competitive while experiments with higher-temperature, point-focusing systems are being conducted on a large scale. To get 3 percent of U.S. energy from high-temperature solar collector systems from renewable resources by the year 2000 would require

The Department of Energy has sponsored the electrification of the entire Papago Indian village of Schuchuli in a remote part of Arizona. The people of Schuchuli had previously relied on kerosene lamps for lighting and had done laundry by hand or taken it 30 kilometers to a commercial laundry; they could store no perishable foods or medicine because they had no refrigerators. Now, a 3.5-kilowatt photovoltaic system, coupled with battery storage, powers 15 small refrigerator-freezers, a washing machine, a village water pump, and lights for the 15 homes, church, and feast house.

growth in installed capacity by a factor of almost 10,000. While the technical obstacles to meeting this projection are surmountable, costs would have to be reduced by a factor of two.

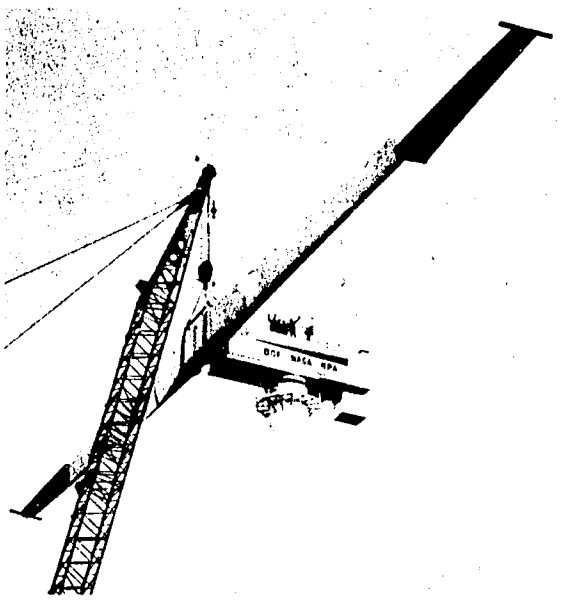
Solar—or photovoltaic—cells produce electricity directly from sunlight. Solar cells operate on the principle that electrons can be "knocked loose" as light is absorbed in materials whose properties also enable these electrons to perform useful work before they are recaptured. Although it was observed more than 100 years ago that sunlight can be converted directly to electricity, our understanding of this phenomenon is only about 30 years old. After successful but expensive use in satellites for many years, solar cells are now beginning to enjoy wider use in an increasing number of remote-area electrical applications, which leads to reduced system prices as production increases. New markets will open up as the price declines, and the expanded markets in turn can further reduce the price. If projected program goals for the price of solar cell modules and installed systems are attained, the residential market is expected to become important in the late 1980s and the utility market in the mid-1990s. While cell costs must come down greatly for photovoltaic systems to compete in these markets, the necessary price reduction is considered today to be well within the capabilities of industry. If costs do decline as projected, about 1 percent of all U.S. energy production can be met with photovoltaic cells by the year 2000.

Biomass—wood and other organic matter—is the oldest, most widely used, and most varied of the renewable resources. In the United States today more than 2 percent of all energy is derived from this source. Most of this percentage is accounted for by wood burning to produce steam and electricity in the wood products, pulp, and paper industries. A second rapidly-growing use is in wood-fired heaters in homes. Industrial and commercial interest is also rising in gasohol—a blend of gasoline and biomass-derived alcohol. More tentative but also promising is the prospect of gasifying and liquefying wood on a large scale. These applications of biomass would allow industry and homeowners to use fuel from wood and organic waste products to replace expensive imported oil fuels and to augment U.S. supplies of liquid transportation fuels. Biomass is also being converted commercially to methane via a bacterial process known as anaerobic digestion. If these and other processes now being developed (e.g., producing hydrogen and even electricity directly from living matter and the sun) prove commercially viable, the total U.S. use of biomass could quadruple in the next twenty years.

Wind energy—long an important source of energy for water pumps, sailing ships, mills, and electricity generators—today shows signs of revival, especially in electricity generation. A growing industry is developing and producing large and small machines with blades which rotate about either horizontal or vertical axes. Although wind systems are not economical in all locations, they are very economically attractive where winds are strong and regular. Current annual sales in the United States of about 5-10 megawatts are projected to increase about one hundred-fold by the turn of the century.

Ocean energy has a wide appeal because the large quantity of stored energy in the ocean permits the design of ocean thermal systems that can provide essentially continuous power production. Because so much of the sun's energy reaching the earth strikes the oceans, a huge and stable resource is available in the world's warm surface waters. Many industrial researchers believe that electricity can be generated economically and continuously by vaporizing an auxiliary fluid (closed cycle) or the seawater itself (open cycle), using the vapor to drive a turbine, and condensing the vapor with cool, deep ocean water. One small system test of a closed-cycle ocean thermal energy conversion (OTEC) system has been successful. Another large-scale test of heat exchangers is now in progress. If the second is successful, pilot plants should be constructed—first as a land-based or near-shore system to serve island economies that depend heavily on oil, and later as a floating system. OTEC systems could potentially contribute about 0.5 percent of U.S. energy supply by the year 2000.

Hydropower—the generation of hydroelectric power—is often the primary but not necessarily the only objective of large dams constructed to serve a combination of purposes—flood control, irrigation, water management, improved navigation, or recreation. However, many older, smaller dams and generating facilities have been idled in the last half century due to economic forces that are now changing. Today, interest in facilities of all sizes, and especially interest in the renewed use of idled dams, is again growing. Hydropower, saved for times of greatest electric power need, can displace oil generally used to meet peak power demands. It can also be used as a storage medium in conjunction with other renewable resources to assure an entirely dependable supply. The United States anticipates increasing by half its current hydropower capacity of 65,000 megawatts by the year 2000. The energy value of this resource already equals more than 3 percent of all U.S. energy consumption.



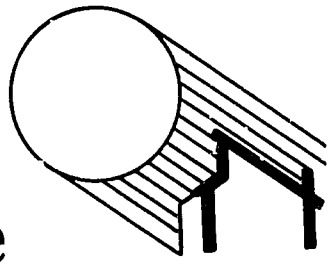
The first of three large Department of Energy-sponsored wind generators was installed in Goodnoe Hills, Washington, late in 1980. More than 60 meters in height, with 90-meter diameter blades, three of these identical machines will produce a maximum total of 7.5 megawatts of electricity in winds of 43 kilometers per hour.

Geothermal energy is the steady flux of heat from the core of the earth to its surface. Three types of geothermal resources being examined are hydrothermal (hot water and steam), geopressured aquifers, and hot-dry rocks. The United States is currently exploiting only those few areas where geological features combine to produce high-temperature steam. The further development of hydrothermal technology is the present focus of the U.S. geothermal program. Federal tax credits, loan guarantees, and technology development have accelerated the growth of the geothermal industry with the aim of greatly expanding the geothermal contribution by the year 2000. Commercial-scale use of the United States' enormous geopressured resources may begin in the late 1980s, and that of hot-dry rock resources a decade later.

Oil shale and tar sands—more difficult to extract than liquid petroleum—can be released under high temperatures, either in place or after mining. In situ extraction has been the central focus of the U.S. national oil shale and tar sands program. Private companies—especially active after the creation of a national Synthetic Fuels Corporation—have also been exploring both in situ and conventional extraction processes. Rapid growth is expected in the Rocky Mountain states where the oil shale and tar sands resources needed to produce these synfuels are available.

Taken as a whole, technologies for harnessing these new and renewable energy sources are becoming better understood and are gaining increasing acceptance in the U.S. energy market. Widespread private and public support leads to optimism about their future success.

Chapter 2
Solar Collectors: Low Temperature



Introduction

When most people think of renewable energy—especially solar energy—they have in mind flat-plate collectors. Utilizing the "greenhouse effect," these collectors absorb the sun's rays, convert them into thermal energy, and restrict the energy from being reradiated. The captured heat energy can then be transported away from the absorber by means of a heat transfer fluid (liquid or air) for either immediate or later use. In many cases, no moving parts are required in this transport: natural conduction or convection forces are sufficient. But even with motors and pumps, a low-temperature solar thermal system is one of the simplest and safest of all energy-conversion approaches.

Historically, there is a great deal of evidence that many societies and cultures developed practical methods knew how to increase their physical comfort through design and location of their housing. Ancient peoples knew how to locate doors, windows, storage masses, overhangs, courtyards, wind breaks, and movable insulation to take advantage of the sun's energy. When it became known that glass readily transmits visible light but is resistant to the transmission of thermal (infrared) radiation, that knowledge too was incorporated into basic greenhouse designs. Early Romans heated their baths with solar energy and feudal lords used it to grow tropical fruits in the winter. These principles of architecture are again being applied to our modern buildings.

This use of structural components to collect and utilize solar energy is termed passive solar architecture. ("Passive" implies the use of few or no moving parts.) Large sun-facing windows are a form of passive solar design, one that relies on the direct incidence of sunlight. (A passively heated home requires a collector area approximately one-tenth to one-fifth the size of the home's total floor area.) As in greenhouses, these direct gain features must be controlled to prevent summer overheating, minimize night-time energy losses, and allow the controlled release of energy when it is needed.

Other forms of passive solar design involve indirect heating—that is, the sun warms the living space without striking it directly. With special design, a vertical wall or horizontal roof surface can, for example, serve as a solar collector. Similarly, either can also provide the cooling if movable insulation permits heat radiation to the night sky while preventing heat absorption during the day.

A shoe company in Vermont uses passive solar energy in its 22,000 square-foot office. Shutters have been installed on the south-facing windows. Natural lighting provides 40 to 50 percent of the building's lighting needs. The 60,000-square-foot warehouse also uses natural lighting and has a large south-wall collector. A glass pedestrian bridge connecting the two buildings also acts as a solar collector, while a thermostat controlled fan governs the heat distribution. In addition to lighting, this solar system provides 34 percent of the buildings' annual heating needs.

A passive technique can also be used to heat water. Thermosiphon units operate entirely by natural convection and gravity. Incoming water is heated in the collector: as the water gets warmer, it rises to the storage tank where it displaces cooler water (at the bottom of the tank). This cooler water flows to the collector, is heated, and returns to the storage tank; progressively getting warmer in each pass through the collector. Suitably designed, a collector of this sort can provide much of the heat needed for domestic hot water uses, even on the coldest of days. Night-time freezing hazards have, however, led most Americans to choose active rather than passive solar water heaters.

Active systems utilize collector arrays attached to the outside of a building and they pump liquid or gas fluids through heat exchanger passages in the collector. This requires the use of pumps, valves, and control systems, along with provisions for freeze protection when liquid heat transport fluids are used. About eight square meters of collector can provide most of the hot water requirements for a typical family of four.

There are advantages and disadvantages to the use of either liquids or air in a solar heating system. Unlike liquid systems, air systems do not freeze, and small leaks do not present serious problems. However, air heat transfer ducts and pumps are larger than liquid systems, since air does not transfer heat as efficiently as a liquid does. Air collectors can compete economically with the liquid systems in most climates.

Another type of collector increasing in popularity is the ground-level solar pond. One model is based upon the principle that in a non-uniform salt-water solution the hottest, saltiest levels stay at the bottom with cooler, diluted levels at the top. If a black absorbing surface is placed on the pond's bottom, the solar energy can be trapped and retained for later use. Other types of ponds use no salt—a distinct advantage since salt is corrosive, can be expensive, and is potentially polluting. Instead, they are covered with insulation at night or their contents are drained into an insulated storage container each evening.

Low-temperature technology includes temperatures up to approximately 150°C for some special collectors having very modest concentration ratios. These include non-tracking collectors like compound parabolic concentrators with concentration ratios of 2 to 10, evacuated tube collectors, and flat-plate collectors with associated reflectors having concentration ratios of less than 2. Efficiency is improved because the surface area from which the losses can occur is less than that of non-concentrating collectors with comparable collection area. Evacuated tube collectors include a vacuum between the two tubes to reduce the thermal losses.

A brewery in Florida has installed an evacuated-tube solar system. The system uses 43 square meters of collectors in conjunction with a phase-change storage system to heat water to more than 60°C for use in the pasteurization of beer. This privately funded $500,000 project has been in operation since early 1978.

This simple air-based vertical-wall solar system is being used at Kansas State University to preheat ventilating air for a pig-farrowing barn. The horizontal reflecting panels increase the annual collected energy by about 15 percent.

Overall, the design of low-temperature systems depends most strongly on how much sunlight (insolation) strikes the collectors. Other important variables affecting design are the local humidity, wind, temperature swings, and the degree of control the user wants over the system.

In summary, the three keys to the efficient collection of low-temperature solar energy are the judicious use of transparent glass or plastic, the reduction of heat loss, and the movement of captured energy so it can be used or stored. Based on these principles, many types of systems are being developed to satisfy America's needs for low-temperature energy.

Applications and Status

In the United States, low-temperature active and passive solar systems for heating space and water can meet most building energy requirements. Although the total number of solar facilities is still less than 1 percent of all potential users, the basic requirements for a successful commercial industry are in place: a well-developed industry infrastructure and a market in which the new products can compete successfully.

In agriculture, requirements for low-temperature heat are substantial, especially for crop drying. Yet, only a few hundred solar crop dryers are now in use since the need is not year-round and do-it-yourself systems require farmers to invest considerable time building and installing the system.

In industry, where low-temperature heat is needed year-round, low-temperature solar applications have seen some modest commercial growth. A promising approach is the solar pond, which may become a major future supplier of solar industrial energy, perhaps ultimately for generating electricity using low-boiling-point fluids (such as freon) to drive turbines.

Low-temperature solar technologies can also be used for cooling. Since the need for cooling peaks when insolation is greatest, and since using a collector to both cool and heat is often more cost-effective than a single purpose unit, solar-powered cooling has considerable attraction. The present drawback is high cost; fewer than 100 systems that are not Federal demonstrations operate in the United States.

If people want the air temperature in residential and commercial buildings to be fully controllable and hot water to be available at all times, either a large storage system or a back-up system will be needed. But, if they are willing to tolerate a temperature variance of a few degrees, or if they will adjust their hot water usage to correspond roughly to the availability of sunlight, they can use a 100 percent solar system at lower cost. Alternatively, they

can choose to meet only a portion of their energy needs with solar sources. In varying degrees, the user is presented with such choices for every renewable energy technologies whose source is intermittent.

Economics

Low-temperature solar thermal systems are a market-ready technology. Least expensive are the simple design changes an architect can make in the placement of windows and overhangs in new buildings. Indeed, these changes can be money savers from the start, if they enable a building owner to install a smaller heating plant than would otherwise have been needed. Skylights, greenhouses, sunspaces, and other passive design features are beginning to earn a wide following on both aesthetic and financial grounds; repaying the costs of these features through fuel savings can be accomplished in only a few years.

Also cost-effective in some cases are simple bag-like air collectors for crop drying. Some farmers can recoup their investments in as little as a year or two.

Water heaters may have a payback period as short as four years in special circumstances. Although costs of installed solar water-heating systems are generally above $300 per square meter, the cost is justified when the alternative is electricity, especially in view of the 40 percent Federal income tax credit and additional tax advantages available in many states. Active space-heating systems tend to be somewhat cheaper than water heaters on a per-square-meter basis, but they must be larger. On the other hand, paying back the initial investment on these systems may take longer than for water heaters because they are most needed in winter when the incidence of sunlight is lower.

Solar ponds may turn out to be the cheapest of all low-temperature solar collectors (although this finding is largely hypothetical since few have yet been constructed). Ongoing studies and experiments have projected that a cost of $4.00 per gigajoule appears within reach.*

The economics of solar cooling depends strongly on the possibility of using the collectors year-round to provide heating as well. At present, these systems are still significantly more expensive than conventional ones.

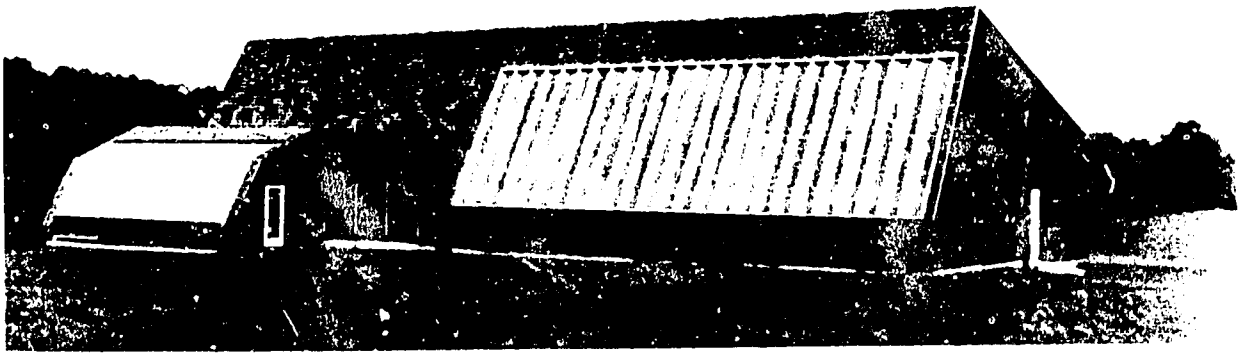
Costs for all solar systems are expected to decline as experience is gained. By some estimates, energy from renewable sources will average $12 per delivered gigajoule by 1985 and $9 per gigajoule by 1990—less even than natural gas might cost by 1990.

A solar energy financing program called the "Safe Energy Fund" has been set up by a San Francisco solar designer and systems installer to provide long-term credit for solar buyers. Those who deposit in the fund collect interest and are assured that their money is being used for a good cause. Loans with a 20-year term are given at a rate that is only 1.5 percent higher than the return given to depositors, which is linked to the yield on U.S. treasury bills. With such financing, active solar equipment becomes more competitive with conventional sources.

Storage and Systems Issues

Heat storage—an integral component of low-temperature solar systems—is required to keep the energy system from overheating

*A gigajoule is very nearly a million British Thermal Units (MBtu). Oil at $36 per barrel is approximately $6 per gigajoule.



This active solar system in Walpole, New Hampshire, provides space heating and water heating for a 370-square-meter commercial facility. The system uses approximately 85 square meters of air flat-plate collectors in conjunction with a 78-cubic-meter rock-storage bin. This system will provide for 100 percent of the facility's heating needs.

during the day and to allow energy carry-over for use when there is no sunshine. In many buildings that require storage the medium holding the heat is masonry; in wooden structures, tanks of water or bins of rocks are often used. Roof-pond systems use plastic bags filled with water as the storage medium. Low-volume but higher priced alternatives to water, rocks, or masonry are chemical compounds that maintain a uniform temperature as they absorb or give off large amounts of energy in changing from solid to liquid or the reverse (much as when ice changes to water).

For many American homeowners, the back-up choice is a wood-burning heater which may be used for only a few weeks each year. More common, though, is continued reliance on the existing electric and gas utilities. This reliance raises the concern that the solar energy user will exacerbate the problem utilities now face where peak demand greatly exceeds average demand. On the other hand, where the largest peak occurs in the summer, solar energy use should alleviate rather than add to the problem, and some electric utilities encourage the use of solar systems with storage as a means of balancing their power loads. In general, since adding capacity is expensive, utilities may increasingly find it in their interest to encourage their customers to "solarize" their homes and workplaces. These overall systems and equity issues are complex; the case of each utility must be analyzed on its own merits.

Barriers and Impacts

Both active and passive systems are typically constructed with low air exchange rates in order to reduce the overall energy demand of the building. In these cases, indoor air pollution is recognized as a major potential problem (which can be somewhat alleviated with an air-to-air heat exchanger).

All the physical and chemical characteristics of typical solar water- and space-heating systems are well known, and few pose environmental or health risks. Moreover, standards have been established through Federal and local regulations for potable (drinkable) water systems, and leakage can be controlled by double-walled containers.

One possible pollution problem is safely getting rid of the collector's spent working fluid or storage medium. Public water supplies could be degraded if these fluids are not disposed of properly. One solution is to allow disposal only at approved sites.

With passive systems in some buildings, indoor air contamination could result in buildings with low air exchange rates, though the problem can be somewhat alleviated with an air-to-air heat exchanger. Similarly, storage tanks could gather mold, bacteria, virus, fungus, and mildew and may therefore need some attention.

A third potential problem with passive systems is glass breakage. But this drawback scarcely seems insurmountable given the availability of tempered glass and plastic glazing.

A work-related hazard stems from the need to handle potentially toxic fluids in the construction of some solar systems. Similarly, some systems could emit toxic chemicals if fires or overheating occur during either construction or use. Although regulations are not widespread, several states have established collector standards.

The lack of assurance of continued access to sunlight may present another problem. Some cities and states have prohibited shading of existing solar collectors; others have encouraged the use of legal agreements between potentially affected parties or have established local height restrictions. Until solar access is guaranteed by statute, collector sales will be inhibited in some areas.

With respect to mining, refining, or guaranteeing the supply of resources needed to fabricate low-temperature solar technologies, the risks appear to be minimal since all the materials likely to be used are common. The United States imports much of the aluminum it uses, but glass and plastics supplies are considered plentiful.

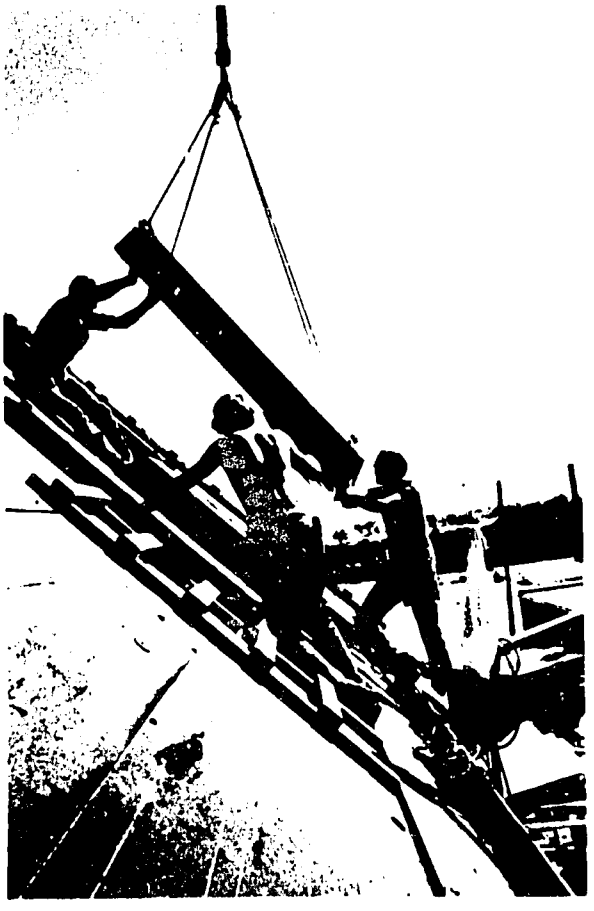
Private Activities

More than 200 U.S. companies are now manufacturing low-temperature active solar systems for heating space and water. Of these, the ten largest have approximately three-quarters of the business. An estimated 7,000 companies are involved in installing low-temperature active systems. Many of these companies are heating or plumbing businesses that have added a solar line.

Collector sales records show phenomenal market growth. Approximately two million square meters of collectors were sold during 1980, totalling about $150 million. Of this total, about 30 percent were domestic hot water applications and 70 percent were lower-temperature systems. These sales represent a growth of 23 percent since 1979, and annual sales growth has averaged more than 40 percent over the last five years.

Passive system use is harder to gauge than active system use. Many architects have enthusiastically embraced passive solar design, but their influence has not yet been felt everywhere. Still, many new companies are now manufacturing and selling greenhouses. Overall, the passive solar industry now receives little direct Federal support, and research conducted within the industry is aimed at product improvement—especially at making the systems more dependable, durable, and controllable.

Key to the near-term future of solar technologies, particularly solar water-heating systems, is the promotional role utilities play. Some utilities give low-interest or no-interest loans or support other innovative financing schemes to enable their customers to buy solar systems. About 20 utilities (among them, the nation's largest) have such financing programs today. Most utilities are reserving judgment on financing, but nearly all are at least investigating



The installation of solar collectors accounts for a major portion of the cost of a solar system. Because of their weight, individual panels are normally limited to about two square meters. These may be installed manually or with power lifts.

low-temperature solar systems, both on their own and through industry organizations.

Widespread support for low-temperature solar design has also come from private citizens organized into community groups. In most states, solar energy associations have taken on the task of educating the public and government officials. Collectively, by sponsoring informational meetings and preparing material tailored to local conditions and needs, these groups are playing a catalytic role in getting solar technologies into wider use.

Government Activities

Federal activity in the development and commercialization of low-temperature solar thermal technologies has been extensive and diverse. Since the mid 1970s, when residential systems were considered ready for commercialization, government has supported the construction of more than 14,000 residential demonstration units. Now, this demonstration program is nearing completion, and Federal support has shifted to the 40 percent solar tax credit (up to a maximum $10,000 investment).

Federal efforts to reduce consumer costs have been augmented by research and development activities (funded at a level of approximately $20 million annually) on active and passive solar thermal systems. Because of the near-term commercial readiness of active and passive solar systems, the need for information dissemin-

ation and for training programs has been considered to be more important with these technologies than with most other renewable energy options.

Support for low-temperature agricultural and industrial applications—greenhouses, crop dryers, solar ponds, and the like—has paralleled that for the residential and commercial solar programs. All have been the focus of comparable research, development, and demonstrations. Corporate purchasers of any of these technologies are eligible to receive a 15 percent Federal investment tax credit on top of the 10 percent credit available for any industrial capital expenditure.

State and local governments have been more supportive of low-temperature solar technologies than of any other renewable energy equipment. Following California's lead, most states allow buyers of these systems relief from various taxes on income, property, and sales. Colorado has a 30 percent tax credit (which unlike California's 55 percent credit can be added to the 40 percent Federal income tax credit), so Colorado residents receive a 70 percent discount on their solar systems. Some cities, particularly in California, have set up municipal solar utilities to finance these systems for private citizens.

Davis, California, a city of 40,000, is a model of energy efficiency and alternative energy use. The city has passed an energy-efficiency retrofit ordinance and has set standards for insulation and window orientation in new houses. As a result of these measures, per capita electricity consumption has declined by almost 18 percent since 1973. Equally important, for the last year the the city has only approved housing with solar water-heating systems, and three California counties have followed the city of Davis' lead in requiring solar water-heating systems in new houses.

Projections

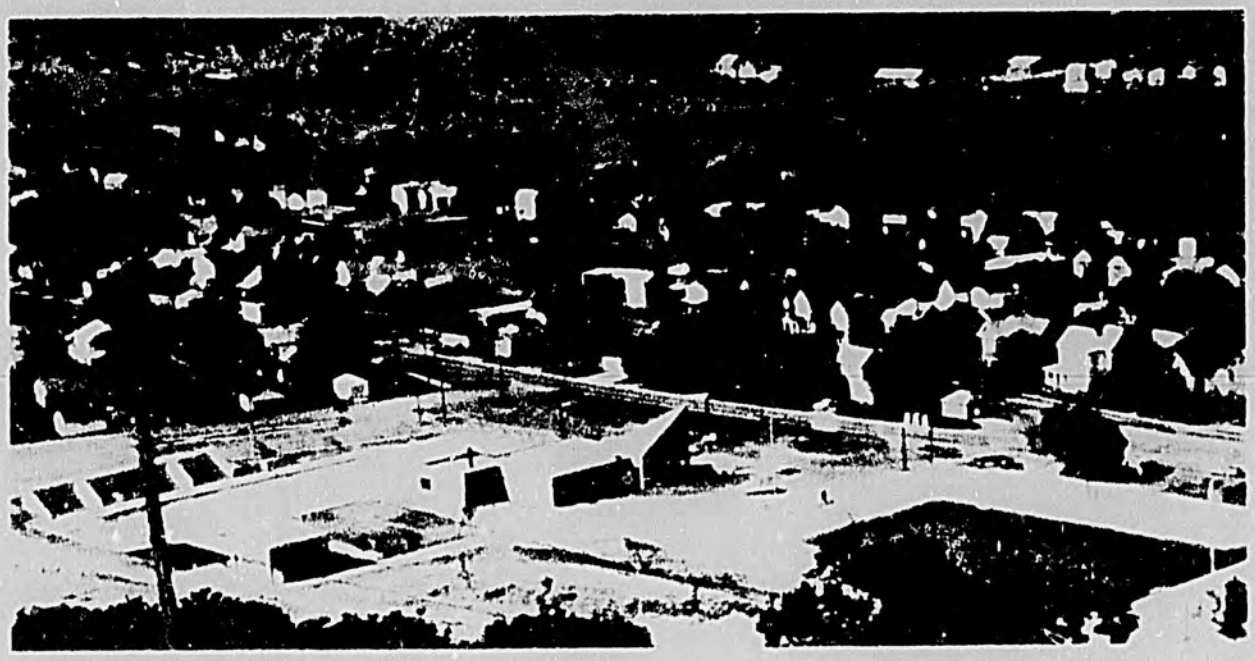
If 20 percent of U.S. energy were to be derived from renewable energy sources by the year 2000, it could mean getting about four exajoules from low-temperature solar thermal systems.* Early estimates indicate that this amount of energy will be allocated in the approximate ratio of 2:1:1 among the active, passive, and low-temperature industrial applications. Obtaining two exajoules per year from active solar heating technologies will require installing solar technologies in 30 to 40 million existing homes, and in more than half of all new homes.

Displacing this much energy will, of course, entail meeting certain cost projections too. If projections for the active solar hot water contribution are to be met, a drop from today's prices ($9 to $12 per gigajoule) of about one-third will be needed. A smaller cost reduction is foreseen for the active and passive solar heating equipment, which presently costs about $12 to $16 per delivered gigajoule. If prices for gas, oil, and electricity rise, many solar systems should become cost-competitive by 1985-1990.

Low-Temperature Solar Thermal in Brief

Present State of Development: Passive-Commercially Ready. Many passive thermal methods have been used for centuries, although some new techniques are relatively untested in practice. ***Active - Commercially Ready.*** Hot water and space-heating systems are operating successfully. Solar cooling technology and applications are limited.

*The exajoule is very nearly equal to a "quad" (10^{15} Btu). The total U.S. energy use is now about 80 exajoules.



A salt-gradient solar pond built by the city of Miamisburg, Ohio, cost $70,000 and provides hot water for a swimming pool and space heating for a recreation center. Over a 10-year period, the cost of heat produced will be $5.75 per gigajoule.

Resource Availability: Passive - Excellent. All materials are conventional and readily available. ***Active - Excellent.*** All materials are readily available.

Fossil Fuel Displacement Potential: Passive - Fair. While new buildings can be designed to reduce thermal energy use, in many climatic regions savings will be minimal. ***Active - Good.*** Solar space heating and low-temperature process heat systems in industry and agriculture can displace a significant amount of fossil fuels.

Cost-Competitiveness with Fossil Fuel: Passive - Excellent. Some techniques involve no additional cost while others entail only minor increases in cost. ***Active-Good.*** Hot water applications are economically competitive with electricity and oil. Active systems are expected to become competitive with deregulated natural gas. Space heating is economically competitive with electricity in the northern United States. Solar cooling is not presently economical.

Degree of Social Acceptability: Passive-Excellent. Properly designed features can enhance appearance of structures. ***Active-Excellent.*** Most systems can be integrated aesthetically into the building structure.

Environmental Acceptability: Passive-Excellent. The concern for indoor air pollution requires care in engineering to minimize potential problems. ***Active - Excellent.*** Handling of some waste products may require proper procedures, but poses no problem.

Institutional Barriers to U.S. Commercialization: Passive - Few. Some resistance to modifying local building codes exists. Solar access legislation may be required. ***Active - Few.*** Barriers may require some

modification to local building codes and solar access legislation.

Availability of Financing in the United States: Passive - Excellent. Only minor additional costs involved. Fuel savings make modification attractive. ***Active-Good.*** Federal and state tax credits are available for individual users, and investment tax credits are available for businesses. With these incentives, financing is available for hot water systems in regions with high insolation and/or high energy prices. Space heating and process heat financing is more limited.

Availability of Information in the United States: Passive - Good. Principles are well understood, although data on optimum design are not readily available. ***Active-Good.*** Detailed information on lifetime, reliability, costs, and design are available.

Chapter 3
Solar Collectors: Intermediate and High Temperature

Introduction

Solar systems that concentrate sunlight can achieve temperatures exceeding 1000°C. The effect of the intense concentration of sunlight is illustrated by a magnifying glass that can focus direct solar energy to a small area and cause a fire. Solar concentrating systems can be built in various sizes to harness heat from the sun for applications demanding these higher temperatures.

Lenses and reflectors to concentrate solar radiation have been used in laboratories to supply a clean, intense source of high-temperature energy for centuries. However, attempts in the early 1900s to power steam engines with solar energy never passed the prototype stages; cheaper alternatives existed and the solar source could supply power only intermittently. However, new concentrating techniques and storage materials along with new fabrication approaches are making higher-temperature solar collection practical and increasingly attractive for industrial process heat, electricity generation, mechanical energy, heating and cooling, or fuel production.

At least five different techniques for concentrating solar energy are being developed. One is to align a series of flat mirrors at the proper angle to reflect the sun's rays to a fixed receiver. These mirrors track the sun to keep sunlight focused on the receiver. This system is called the "power tower" because the receiver is usually supported on a tower. It is expected to be the lowest cost solar thermal means for producing large amounts of power.

A second technique involves tracking the sun with a "parabolic dish." Looking and functioning much like large radar antennas, the dishes can achieve temperatures exceeding 1000°C on an absorber surface at the dish focus. If a heat engine is placed at the focal point, converting heat to electricity can be highly efficient. Alternatively, a heat-activating chemical reaction can transfer energy away from the focal point. The parabolic dishes are excellent for dispersed applications of process heat and electricity. Community electric systems of less than 10 megawatt size appear to be an attractive market for parabolic dishes in the 1990s.

A third technique entails the use of linear "parabolic trough" mirrors curved in only one dimension. With the focus as a line rather than a point, parabolic trough systems can produce heat at temperatures up to 300°C and are cost-effective for many applications. Moreover, it is relatively easy to track the sun in only one dimension and to form and mechanically support the curved mirrors. The same effect can be achieved with a series of movable slats that simulate the curved trough.

The fourth technique relies on the use of fixed "hemispherical bowls" with movable receivers. Although the concentrated energy obtained with the bowls, which are sunk in the ground, is not as intense as that obtained with a parabolic dish or the power tower, having the mirror fixed in place affords mechanical advantages. A linear system with fixed facets and a movable receiver is also being developed.

Another technique to concentrate solar radiation is with magnifying lenses. Because a solid lens would have to be extraordinarily heavy to be big enough to produce power in large quantities, a modified lens is being developed. Molded in plastic, this stepped "Fresnel" lens is no thicker than a pane of glass, but it concentrates as though it were many times thicker. Like mirror concentrators, it can focus to either a point or a line and must track the sun continuously.

In the first four techniques, the reflector used is most often a silver-plated, weather-protected glass mirror. Alternatives being developed include those made of polished aluminum, plastic films, and glass "sandwiches." The support structures are made of plastics, wood, metal, concrete, or foam glass, while the focal-position receivers are made of glass, ceramic, or metal. Oil, water/steam, air, liquid metal, or liquid nitrate salt carries the heat away from the receiver.

Either the receiver or reflector (or lens) surface must track the sun at approximately the 15° per hour rate at which the earth rotates. Accurate tracking requires sun sensors, motors, and a logic or clock system to compensate for blockage of the sun by a cloud. Although the search for new construction materials and for new approaches continues, these systems concepts are well understood. The main technical difficulties remaining are increasing the lifetime and reliability of components.

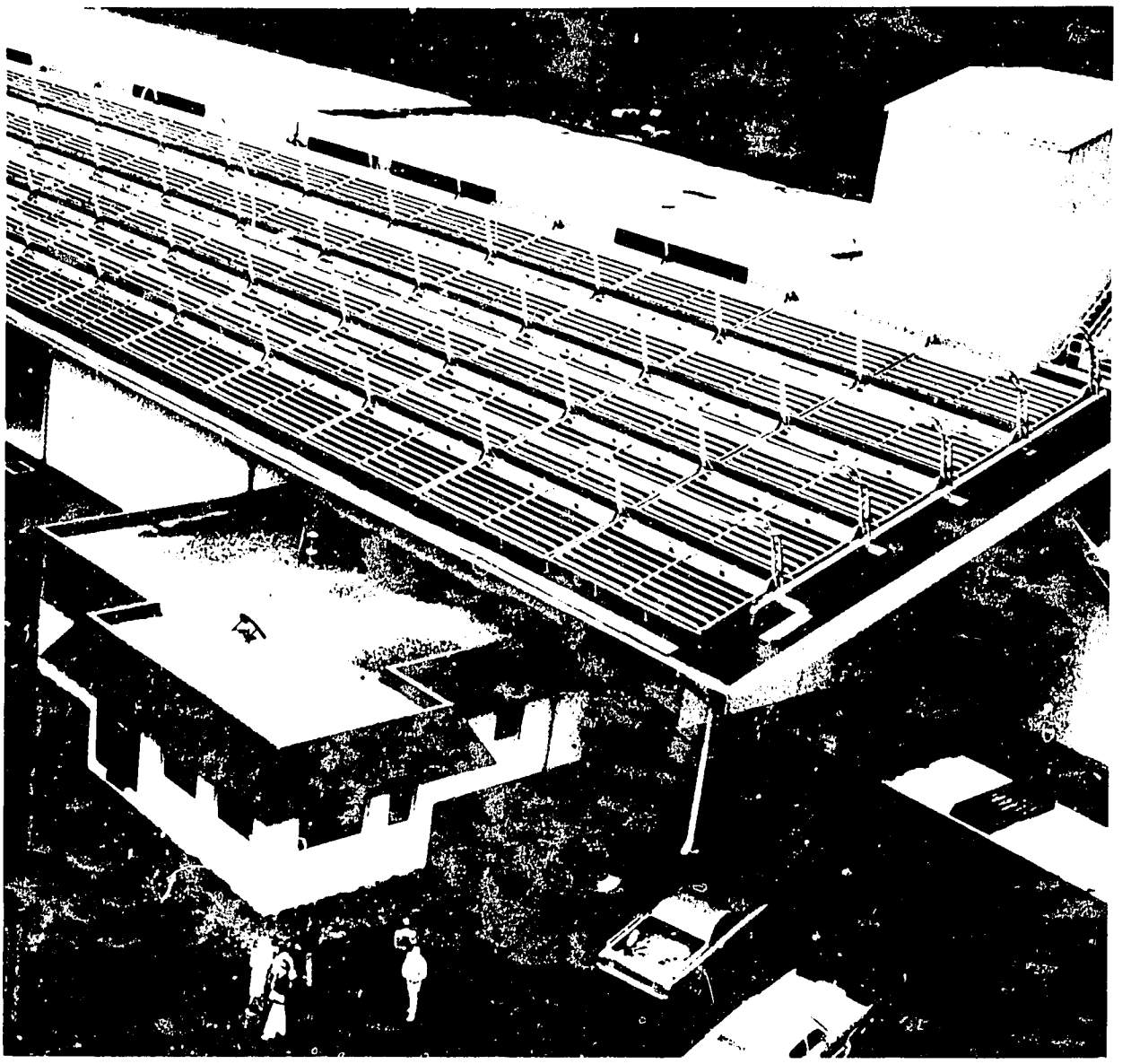
Applications and Status

Many industrial process heat applications need temperatures up to about 300°C. Parabolic troughs are ideally suited for these applications. Parabolic dishes and central receivers that can attain temperatures greater than 1000°C can be used for large-scale electricity generation and for production of fuels and chemicals. Solar thermal systems provide heat energy that can be used directly or can be converted to other forms of energy.

A solar thermal system can satisfy a variety of needs ranging from process heat and electricity to space heating, hot water, and space cooling. In some applications, heat is first used to generate electricity, then the "waste" heat is used for an industrial process or space heating. This dovetailing—solar cogeneration as it is known—will be put to an industrial test for the first time in 1981, when a "total energy system" is installed at a textile factory in Georgia.

Another potential near-term industrial application of solar thermal heat is for the recovery of oil. Steam produced in parabolic trough collectors or central receivers can be piped underground to release oil that is too viscous to pump out economically by any other means. This solar approach entails a double dividend, obviating the need to burn oil to produce steam and minimizing pollution.

Utilities may prove to be an important future user of central receivers or parabolic



In this demonstration retrofit system in Harrisburg, Pennsylvania, a glycol/water mixture is heated to about 80° C using about 850 square meters of 24-to-1 concentrating collectors. The glycol/water mixture is used to heat water to 60° C to cure concrete blocks. The system has saved an average of $70 per day since beginning operation in late 1978.

dish solar thermal systems. For facilities with more than 10 megawatts of generating capacity, the power tower is seen as the most appropriate option, while the use of parabolic dishes makes more sense in smaller utilities. Two central receiver systems, one located in Barstow, California, and another in Almeria, Spain, are under construction and will begin operation by the end of 1981. The Barstow 10-megawatt facility will be the world's largest solar power plant. In Almeria a 500-kilowatt power tower is being built next to a line focusing system of the same size. Dish systems await testing by several small utilities—a critical venture since alternatives to small oil-fired electrical generating stations are needed.

Using solar concentrators in the production of synthetic fuels is a final important solar high-temperature application, although still in an early development stage. While no practical approaches have yet been developed, hydrogen production by thermal decomposition of water into

hydrogen and oxygen is one such possibility.

The market for tracking solar collectors holds great promise, although few systems have been sold commercially, primarily because of current high cost. For the moment, most systems are being constructed in field tests, usually with Federal funds.

Economics

Since high-temperature thermal systems have yet to be widely produced, any discussion of their economics is hypothetical. For instance, installed systems are available at about $200 to $400 per square meter of mirror surface, but prices are expected to drop considerably within a few years as mass production and experience establish new technologies. Thus, while the equivalent energy cost is today almost $25 per gigajoule, it is projected to fall to about $8 to $10 per gigajoule by 1990 and to $5 to $7 per gigajoule by the year 2000 (in 1980 dollars).

Storage and Other Systems Issues

Storage options for high-temperature systems are much more diverse than the water-tank, rock-bed, and chemical compound approaches used in low-temperature solar systems. For example, pressurized water or steam can be used for storage, although costs escalate with the temperature (and pressure). Storage in oil is practical but only up to the temperature at which the oil decomposes. Scrap metal, slag, bricks, and sand have also been proposed as thermal storage media.

For industrial process heat applications, the storage must be on site. To date, industrial solar thermal storage is little used because it costs more than back-up fuels. For solar thermal electricity generation, the storage can either be on site (thermal) or located elsewhere in the electric grid (perhaps as pumped hydro). In either case, some on-site thermal storage is required to compensate for short periods of cloudiness and to accommodate the electricity demand peak that occurs daily just after dusk.

Barriers and Impacts

Large high-temperature systems require expanses of land, although in some industrial applications rooftops and parking lots will suffice. However, these systems generally require less land for the amount and quality of energy produced than other renewable energy technologies. In any case, if the negative effects on and from neighboring activities are to be minimized, the area may have to be larger than the approximate 0.7 hectares of land required for the capture of one peak megawatt of thermal energy. Since many industrial systems will be deployed in populous areas, conventional land-use plans may have to be modified to prevent shading the collectors. In residential and commercial areas, community solar systems may also violate current zoning codes.

Many of the first electricity-generating systems may be built in desert areas. Constructing and maintaining large fields of heliostats may change native plant and animal communities, as well as affect surface water and groundwater. Treating the soil to control dust or plant life may also lead to such secondary effects as flooding and water pollution.

The effects of changing the microclimate, apart from displacing indigenous plants and animals, remain unclear. Increasing shade will certainly reduce evaporation, which could benefit agriculture. But most positive and negative effects remain speculative because of inadequate data. Although microclimatic effects may be limited for a single facility, further data need to be collected and analyzed.

Dedication ceremony participants stand next to one of the 2000 heliostats on 50 hectares of land surrounding a 100-meter-high central tower at the Barstow 10-megawatt electric pilot plant. When it becomes operational in 1981, Barstow will be the largest operating solar thermal electricity generating system. It was dedicated in October 1980.

During operation, high-temperature solar systems may employ heat-transport and storage media, the use of which entails potential fire and environmental hazards. Care must therefore be exercised in the use of these systems, especially within the food industry. Also, heliostats or other concentrators may cause burns, eye injuries, hazards for nearby ground and air traffic, and fires. Accidents to date have been minor.

The construction of larger facilities may disrupt local community and economic life, though much more of the labor will be in factories than with most large power facilities. In some modular approaches to power-plant design, plant construction can be phased to coincide with power needs. In general, social disruption should be manageable.

For utilities, the use of solar concentrators may also affect daily operation. It may be useful for utilities to be involved in the planning of large on-site solar systems to minimize the impact on load and/or to provide an equitable rate structure.

Private Activity

About ten commercial manufacturers of tracking trough-concentrator systems have sold enough systems to supply about 25 thermal peak megawatts. Twenty other firms are involved in Federally sponsored research on troughs, and most of these will probably be future suppliers as well. During 1980, total sales were about 50,000 square meters with a value of about $20 million. Approximately half were sold, without Department of Energy funding, to corporations and individuals eager to begin assessing the potential of solar thermal process heat systems.

A small quantity of central receiver systems and parabolic dishes is sold to the private sector, although most of them are sold to the Federal Government. Approximately 40 companies are involved in research on these technologies, with at least ten preparing to sell their technology commercially.

Government Activities

The various technologies for concentrating sunlight are being supported in different ways in the Federal solar thermal program and are expected to be commercially ready

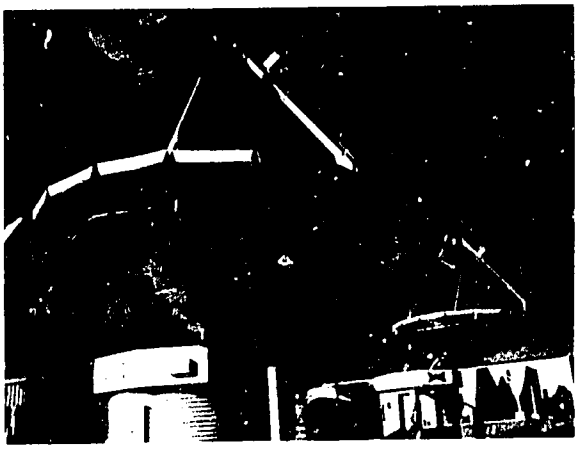
by the mid- to late-1980s. Troughs and fixed-reflector systems are now being developed for use in industrial process heat applications and are being demonstrated in various settings. The emphasis here—sustained through a 25 percent investment tax credit (15 percent larger than the usual investment tax credit)—is on creating a technological base to allow development of a viable solar thermal industry. Past funding by the Federal government on trough concentrators for industrial process heat has amounted to approximately $35 million annually.

Although government support of central receivers has been oriented primarily toward utilities' needs, central receivers can be used for industrial process heat too. With about $35 million per year going to this central receiver effort recently and another $35 million into the smaller dish systems for utilities and industrial cogeneration, most support has been for technology development.

Research and advanced development activities have received about equal emphasis. This investment is directed to developing lower cost, more durable, and more efficient components.

Projections

Estimates of potential impacts indicate that up to 3 exajoules per year may be obtained from high-temperature solar thermal systems in the year 2000. About 0.4 exajoules per year of this total could be for electricity production, with the remainder for process heat applications. In this case, the installed electrical power would amount to between 10 and 15 gigawatts (depending on storage), or about 2 to 3 percent of all electrical production capability. The solar industrial process heat contribution might be about 8 percent of the total industrial energy demand, which is now about 30 exajoules per year.

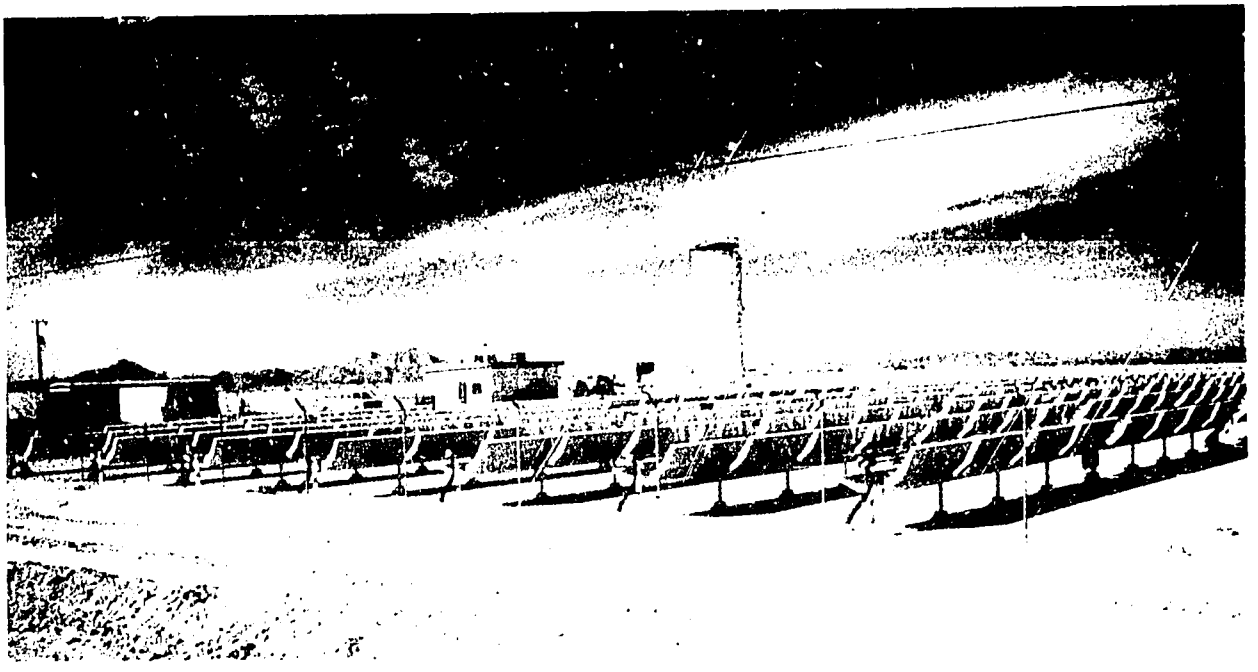


These two parabolic dishes are being used at the Solar Energy Research Institute in Golden, Colorado, for optical and thermal testing of advanced receiver concepts.

To achieve these energy production levels, costs would have to be about 5¢-6¢ per kilowatt-hour for electricity and $4-$7 per gigajoule for industrial process heat in the year 2000. These costs are slightly higher than average energy costs in the United States today but less than the costs of power obtained from new additions to energy capacity. The cost of heliostats, troughs, and other concentrators would have to fall to about $70 to $100 per square meter in 1990 (in 1980 dollars), if high-temperature energy-production levels are to be met.

Solar Collectors — Intermediate and High Temperature in Brief

Present State of Development: Demonstration Stage. Troughs are commercially available. Central receiver systems are in the demonstration stage. Dish systems are technically sound and awaiting demonstration in community-scale systems.



This Arizona project is the first large-scale demonstration of solar concentrators to pump irrigation water from a deep (115 meters) well. Trough collectors power a Rankine cycle engine to provide electricity for these pumps, which can lift water from the well at a rate of almost 90 liters per second to irrigate more than 800 hectares of land.

Resource Availability: Good. All fabrication materials are the stock-in-trade of the manufacturing industry—steel, concrete, and glass. Alternative reflector surfaces such as aluminum are being investigated. Land availability may be a problem in industrial process heat applications in populated areas.

Fossil Fuel Displacement Potential: Very Good. Solar thermal systems provide heat that can satisfy industrial process heat requirements and can be converted to electricity in community and utility applications.

Cost-Competitiveness with Fossil Fuel: Good. Solar process heat costs are projected to decline to less than $10 per gigajoule by 1990. Electricity generation may be competitive in the southwest for oil-dependent utilities.

Degree of Social Acceptability: Good. Large electricity generating systems will be away from population centers. The use of concentrator systems in highly urban areas may be limited.

Environmental Acceptability: Good. Some concerns have been raised regarding potential harm to the desert environment, but these are not significant when compared to the environmental effects of conventional energy systems.

Institutional Barriers to U.S. Commercialization: Few. Regulations, land use issues, and the use of large reflective surfaces pose some barriers to use of high-temperature solar thermal systems.

Availability of Financing in the United States: Fair. Large capital investment

requirements and low rate of return contribute to moderate availability of financing for industrial proces heat applications. Utility investment in solar thermal requires demonstration of reliability, performance, and operation.

Availability of Information in the United States: Fair. Information for parabolic trough system operation is available. However, central receiver systems and dish systems have yet to be demonstrated in an operating environment.

Chapter 4
Solar Cells

Introduction

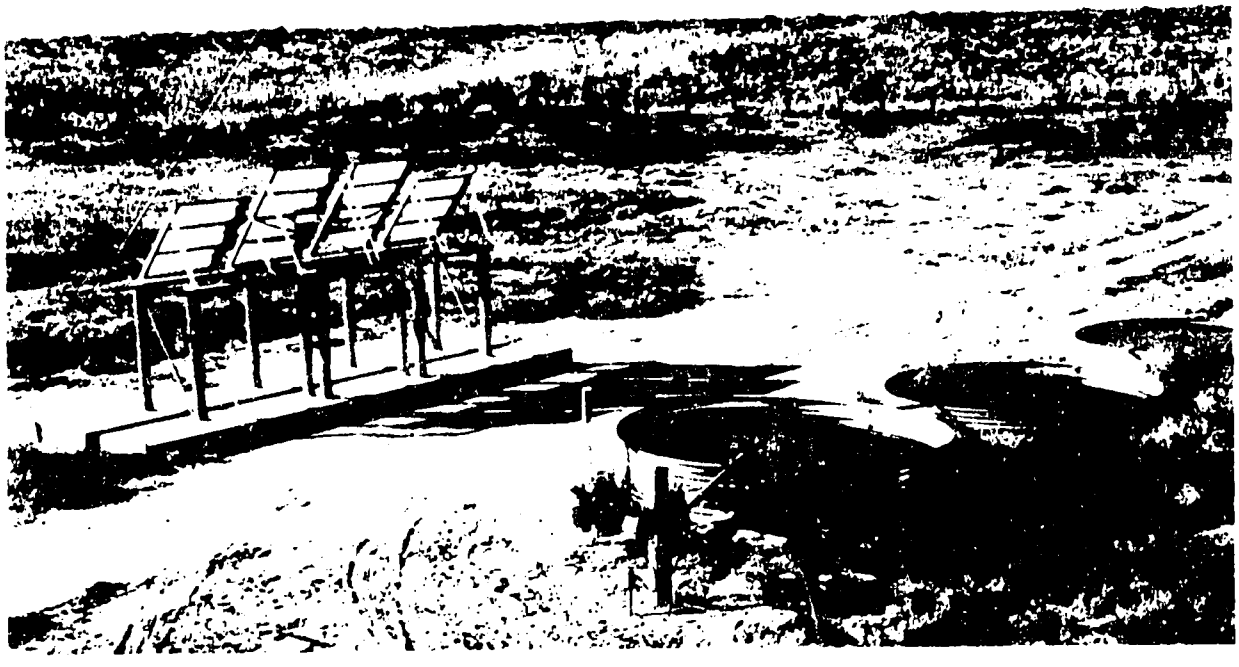
Photovoltaic energy systems use photovoltaic (solar) cells to convert sunlight directly into electricity. These cells require no complex rotating machinery, no heat engine cycle, and no intermediate conversion of solar energy to heat. Their intrinsically modular design allows system sizes to fit almost any need. Concepts of photovoltaic systems include both flat-plate collector panels with no concentration of sunlight and concentrating panels using mirrors or lenses.

Photovoltaic cells, the essential element of the system, absorb sunlight and convert it directly into electricity. The cells are constructed by combining two thin layers of semiconductor materials; one layer has negative electrical properties, and the other has positive. Examples are silicon, with two different trace elements (homogenous junction), or cadmium sulfide and copper sulfide (heterogenous junction). When light photons of sufficient energy strike the cell, they dislodge electrons from the atoms, leaving "holes" in the structure. The free electrons moving across the junction create voltage in the cell, due to the inherent electrical properties of the cell junction. Terminals of an external circuit are attached to the front and back of the cell so that the current generated can be drawn and used for power.

Single-crystal silicon solar cells are fabricated commercially in many sizes and shapes and then placed in larger supporting structures called modules. Modules are generally flat structures containing many interconnected cells (commonly from 10 to 100) and having solar collecting areas of 0.1 to 2 square meters. The modules are themselves mounted in photovoltaic arrays, which combine with other associated subsystems to form a photovoltaic power system.

In addition to the arrays of solar cells, a photovoltaic system generally contains power monitoring, control, and regulation equipment; storage batteries; and the other controls needed to connect the power to the user. Photovoltaic system power is usually designated in terms of peak watts of electric power output at solar noon on a clear day with the sun's rays striking the collector aperture at 90 degrees to the plane of the aperture.

Most cells that are commercially available today are made from single-crystal silicon. Silicon photovoltaic cells were invented in 1954 following years of use of relatively inefficient selenium cells. When first used in space satellite applications in the 1960s, the cells were very expensive. As the price of the cells was not a primary consideration and as the required quantities were small, the price remained relatively high. However, rapid developments in the electronics industry and intensive support of photovoltaic research and development by the Department of Energy in the last five years have substantially reduced prices. As the price of cells declined, markets for land-based applications began to develop,



This ¾-kilowatt water pump powered by solar cells represents one application for which photovoltaics are now cost competitive. In many remote areas, the costs of transmission lines or diesel fuel already exceed the cost of this alternative.

including remote applications where utility power is not readily available and where the alternative fuel is expensive.

The Southern Railway Company has used solar cells since 1976 for generating electricity to control signals and circuits for drawbridge crossings at locations far from the utility grid. Since 1978, it has also used them to power rear markers on some cabooses. Results have been highly positive, convincing Southern to extend its use of photovoltaics.

Dispersed applications that are linked to the utility grid can become commercially viable by 1986. These include use of photovoltaic systems on residences, and on commercial and industrial buildings where electric power requirements are small. Alternative thin-film solar cells made from semiconductor materials such as amorphous silicon, cadmium sulfide and gallium arsenide, are under intensive research and development. These thin film solar cells offer a potential for significant price reduction to the level where photovoltaic systems could be used for electricity generation by the nation's utilities. The commercial readiness for central station utility applications is projected to occur by the 1990s.

Applications and Status

When used in centralized or decentralized applications, solar cells can meet virtually every need for electric power—for lighting, cooling, running appliances, and other basic electric power needs. (In the United States, homes will typically require 3 to 10

peak kilowatt systems, with commercial buildings needing 10 peak kilowatts to 1 peak megawatt.) Homes are likely to use flat-plate collectors, while commercial structures will use either flat plates or concentrators. Some residences already boast substantial solar cell arrays on their roofs.

The primary agricultural use for photovoltaics will probably be to power irrigation pumps. This solar application is important since irrigation alone consumes about 30 percent of an average farm's energy in the United States. Moreover, the demand for irrigation water is highest when the weather is hot and dry, which is also when solar energy availability is the highest. Photovoltaic systems are also already providing some power for such remote agricultural applications as frost warning systems, livestock watering systems, and electric fences.

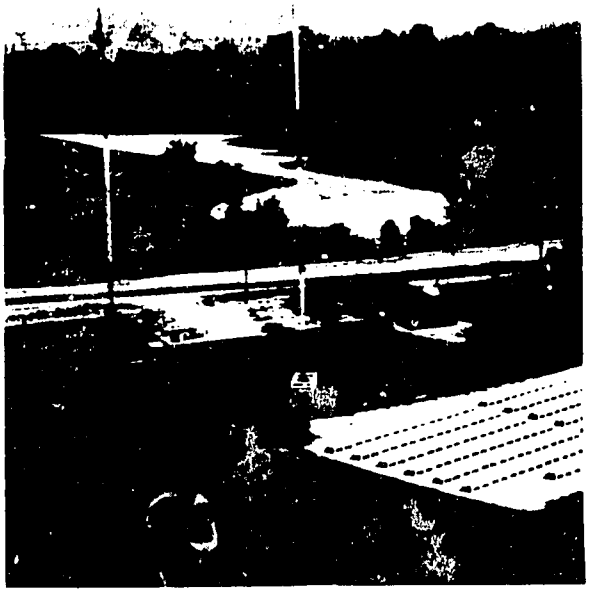
Photovoltaics are also in use in many remote applications, e.g., communications stations and cathodic protection (reduction of metal erosion) of pipelines. Their wider future use in industry appears especially likely in the southern United States, where "total energy systems" can provide both on-site electric power and low- to moderate-temperature process heat. In the near term, photovoltaics may also be used widely in those markets now served by diesel generators or batteries, including remote village applications, street and highway lighting, warning lights, railroad switching and signaling, runway lights, and navigational lights and signals.

Potentially the largest markets for photovoltaic systems will be those applications that have a utility grid backup or systems used directly by the utilities to generate electricity as a part of their own generation capacity. The grid-connected dispersed market consists of small power users including individual homeowners. The ownership of these systems could be either by the users or by the utilities. Photovoltaic systems in most utility markets, those with coal and nuclear resources, will not be competitive until the 1990s.

Another potential application of solar cells would be on large satellites to produce a direct current that could be transformed into microwave or laser energy. After transmission to the earth, this energy would be converted to alternating current for use in a grid. The theoretical advantages of a satellite approach are that solar energy is available almost continously in space and in a greater quantity than on earth. Disadvantages include the large costs of developing and deploying a satellite system, the energy losses associated with the conversions and with transmitting power back to earth, and a number of social and environmental concerns—especially related to potential microwave hazards. Federal funding for the solar satellite for 1981 is low, pending a decision on how to implement the findings of several years of assessments by both the Department of Energy and the National Aeronautics and Space Administration.

Economics

High cost is the greatest barrier to the widespread use of photovoltaic systems. Although the price has fallen dramatically in the last few years—from $50-$60 per peak watt for the installed system in 1976 (about $22 per peak watt for the module alone) to $15-$20 per peak watt today ($6-$10 per peak watt for the module)—today's price translates into roughly $1.00 per kilowatt-hour. Since conventionally produced electricity in the United States now costs the consumer between 2¢ and 10¢ per kilowatt-hour, to be fully competitive for these grid-connected applications, the cost of photovoltaic power must still be reduced substantially.



The world's first commercial radio station (broadcasting only during daylight hours) powered by solar cells is located in Bryan, Ohio. This demonstration system contains 33,000 photovoltaic cells and is expected to satisfy 70 to 90 percent of the station's energy needs.

It will take time for solar cell technology to capture more than its present small market share which is a portion of the electric power needs for remote sites. If the module price falls to about $2.80 per peak watt, photovoltaic systems can become fully competitive for a large part of the remote application market after 1982. Widespread use of these systems in agriculture is not expected until the late 1980s because costs need to be lower in agricultural applications for the technology to be economical.

Photovoltaic systems should be competitive for residential and commercial uses when the module price is about 70¢ per peak watt—roughly one-tenth of today's price. The present rate of technology development and the industry's commitment both indicate that the reduction of module price to 70¢ per peak watt can be achieved by 1986. Before most utilities will find photovoltaics economically attractive, the module price needs to drop to less than 40¢ per peak watt, which it is projected to do in the 1990s. System prices are expected to be approximately three times the cell prices cited above in each year.

A few additional cautions about price calculation are in order. First, because the solar resource varies greatly from region to region, the cost of energy from photovoltaic systems in different regions will vary accordingly. Second, U.S. residents pay relatively low rates for energy. The relative cost of photovoltaics is high in the United States, but for nations whose citizens already pay $1 per kilowatt-hour for electricity, the cells are economically competitive now. The cost of energy from the cells further entails consideration of system lifetime, finance charges, tax considerations, and inflation. Finally, it is incorrect to compare directly the capital cost of a photovoltaic system to the capital cost of a conventional plant. Photovoltaic systems without storage typically operate 20 to 30 percent of the time, while conventional plants operate 50 to 75 percent of the time. Generally the capital costs of solar cell systems (per peak watt delivered) must be lower to deliver energy at a similar price, although these negative factors can be offset to a considerable degree since a solar system is cheap to operate and needs no fuel. Meaningful comparisons must take all these factors into account.

Storage and Other Systems Issues

Photovoltaic power systems for continuous duty in remote locations require associated storage—in most cases, the familiar lead-acid storage battery. Without associated storage, a photovoltaic system can only provide electricity when the sun is shining—perhaps only 20 to 30 percent of a typical application's requirement in the United States.

Electrical energy storage is also important in conjunction with coal or nuclear-fired power plants, which already meet peak loads by drawing upon (primarily hydropower) storage charged during low-demand periods. Because of its importance in both renewable and non-renewable energy applications—and in the development of electric vehicles—electric energy storage is of growing importance in the U.S. energy program.

Centralized energy storage is now primarily through conventional, pumped hydroelectricity (see Chapter 8), but new options include underground hydropower, compressed air, flywheels, and superconducting magnets. For decentralized storage, the primary candidate is the storage battery. For all of these, the cycle losses (to and from storage) for the energy are approximately 10 to 30 percent. In remote applications, these losses may be tolerable because alternatives are more expensive; for other applications, only compelling non-economic reasons currently justify the high costs. In utility applications, the losses and costs may not be justified. In the case of residences already connected to an electrical grid, the decision whether to add storage will be primarily based on the utility time-of-day charges for both buying and selling power. However, if added storage is under utility control, the utility can avoid adding more standby power generation equipment.

Barriers and Impacts

Although price is the greatest barrier to the increased use of photovoltaics, it is not the only one. If solar cell arrays were employed extensively in a decentralized manner, economic and technical problems could arise for utilities. Since the solar resource is intermittent, solar-equipped facilities without adequate storage will need back-up power from a utility, which must then maintain capital equipment to be used only on relatively rare occasions. The costs of maintaining conventional back-up power must be borne either by the photovoltaic user (making such use more expensive) or by all the utility's customers.

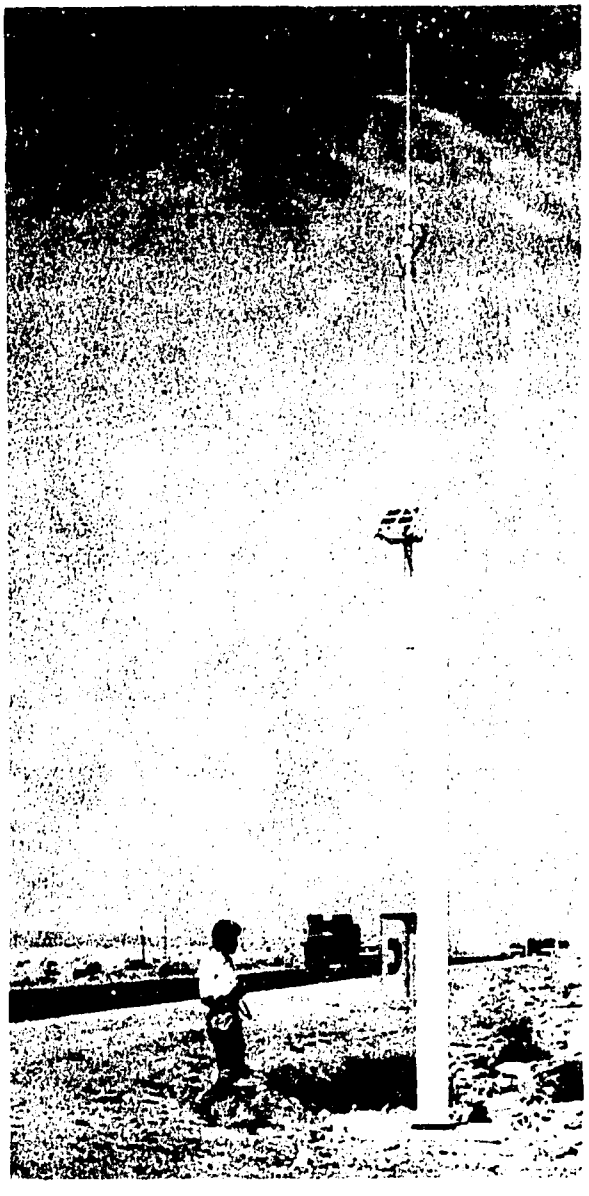
A second utility-related issue concerns small power producers who sell their excess electricity to the utility. Recent Federal legislation requires that utilities pay a price for this electricity that equals the cost they avoid by not having to generate that amount of electricity themselves. Each utility and state regulatory body will have to determine what that price is.

The need for safety features to protect the utility and its customers poses still other issues. If, for example, a small photovoltaic system inadvertently feeds electricity into a utility line shut down for repairs, the situation could be hazardous to repairmen. Other effects of the utility's loss of direct control over photovoltaic systems also need to be determined.

Technological complexity is another concern. The photovoltaic system for residential applications is more complicated than wood stoves or solar water heaters. On the other hand, repair techniques are simple and well known—in many cases, manageable even for the homeowner. Still, the reliability of the technology has not been widely proven under normal operating conditions.

Few environmental concerns about the normal operation of photovoltaics systems have been voiced. But accidents and overheating can lead to environmental problems in the collector and storage subsystems. Environmental questions have also been raised concerning the materials and manufacture of the solar cells. Of specific concern are the potential hazards to workers in the handling of cadmium, selenium, arsenic, and gallium as well as silicon. Disposing of or recycling defective, broken,

and obsolete cells also requires attention. These concerns, however, are considered minor during operation of a system, but careful attention must be paid to control of the raw materials during manufacture of the cells.



Remote highway radio telephones are becoming more common. Power for this seldom-used service can be provided by a very small photovoltaic array whose use greatly reduces the costs of maintaining a battery alternative.

Private Activities

Photovoltaic research and development is presently being funded more by government than by the private sector. Yet, businesses and investors are interested in the technology—as indicated by the increasing amounts of risk capital being ventured in photovoltaic development. About 20 companies now manufacture photovoltaic hardware for sale to the public; among them are both large corporations and small specialized companies. At least six major oil companies have photovoltaic subsidiaries with substantial activities under way in photovoltaic module and system development. By industry accounts, photovoltaic industry sales were on the order of $20 million for about 1.8 megawatts during 1979. Sales more than doubled in 1980, and approximately 50 percent of 1980 sales were in the export market.

There are also ongoing educational activities in the private sector. Many citizens' groups educate people about the virtues of solar energy, promoting photovoltaics and offering "hands on" workshops.

Government Activities

The U.S. Government now provides more funding for photovoltaics development than for any other renewable energy technology. In 1979, the Department of Energy spent about $110 million; that sum was increased to over $150 million in 1980. These funds support research and development, experiments, and systems testing efforts.

Two independent factors are expected to help bring down the costs of photovoltaic systems. One is progress in research and development, which can lower production costs and improve performance. The second factor is increased experiments and

demonstration of specific uses in the United States including Federal experiments. This provides an additional market to encourage private photovoltaic companies to take advantage of economies resulting from mass production and to bring photovoltaic systems more directly to the attention of users. The Federal Photovoltaic Utilization Program (FPUP) was initiated in 1978. In the first two phases of FPUP (1979 and 1980) the government purchased about 3,000 small systems (most of them less than 1 kilowatt each) for the National Park Service, Forest Service lookout towers, and other isolated places where small power systems are needed.

Funding for a 100-kilowatt photovoltaic system planned to provide about 30 percent of the power for a privately owned shopping center in rural New Mexico came in part from the Department of Energy and in part from the Lea County Electric Co-op. Also participating in the project are the New Mexico Solar Energy Institute (a state organization) and private solar manufacturers. This photovoltaics application illustrates a basic principle in federally funded energy programs in the United States: extensive cooperation with and participation by public and private organizations. At a cost of $2.7 million (or about $18 per peak watt), the power costs associated with this system cannot compete economically with those of conventional electric grid systems, but the system does serve as a valuable test experiment to obtain system performance and maintenance data. At the same time, along with other such projects, this system should assist the photovoltaics industry by helping to reduce per-unit manufacturing costs.

Projections

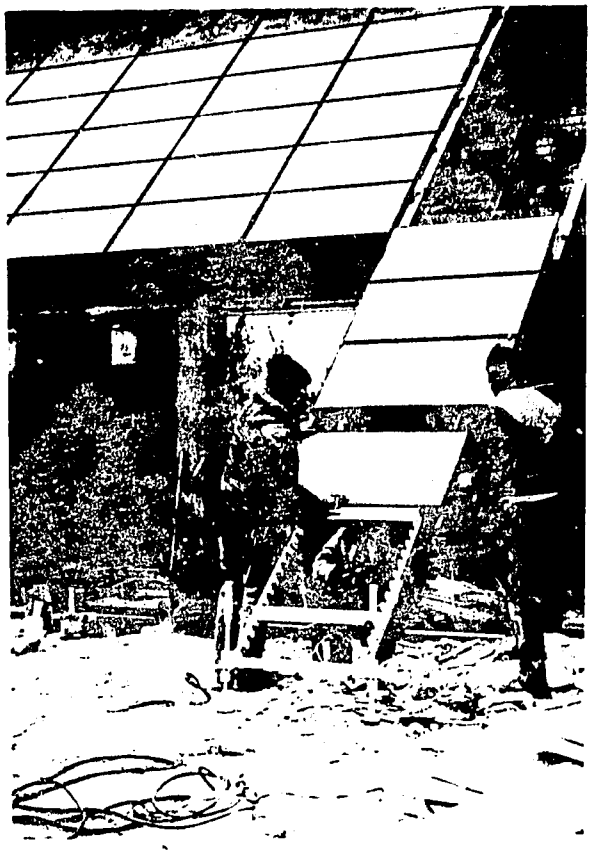
The United States has a diverse program aimed at bringing down the costs of photovoltaics and at helping the industry develop additional markets for solar cells. Specifically, the goal is to bring the current price of an installed system from $15-$20 per peak watt down to about $6 per peak watt by 1982, $2.00 per peak watt in 1986, and $1.25 per peak watt by 1990-2000. (These figures are in 1980 dollars.) The primary uses for systems projected to become cost-effective in 1982 will be those at remote sites in the United States and in the international market. In 1986, applications in residences are projected to become economical; after 1990, utilities are projected to find their applications cost-effective.

If the above cost projections can be reached, estimates of primary energy impact up to one exajoule per year by the year 2000 have been made in some photovoltaic industry studies. This could include 0.3 exajoules in the residential sector (about 2 million systems installed), 0.04 exajoules in the commercial sector (approximately equivalent to the production of one 850-megawatt fossil fuel electrical-generating plant), 0.5 exajoule in industry, 0.01 exajoule in agriculture, and 0.2 exajoule in utilities.

Solar Cells in Brief

Present State of Development: Technically Ready. Cells are manufactured and sold worldwide by about 20 U.S. companies, primarily for remote and international applications. Thousands of systems are operating in diverse environments (largely remote areas) worldwide and are reliable and cost-effective. Further cost reductions and improved reliability and lifetimes are necessary for their widespread use.

Resource Availability: Excellent. Refining capacity for specific feedstocks (e.g., silicon) needs to be increased but resource availability is not expected to be a constraint for present silicon-based technologies.



Photovoltaic panels now are beginning to be installed and tested in the United States on residential structures such as this test unit at the Florida Solar Energy Center.

Fossil Fuel Displacement Potential: Fair. Solar cells are attractive in dispersed applications. However, the fossil fuel displacement is not large.

Cost-Competitiveness with Fossil Fuel: Good. For most remote market needs for electricity, photovoltaic systems are competitive with alternative systems requiring transportation of fossil fuels, e.g., oil for diesel engine-generators. Photovoltaic system prices are expected to decline substantially in the next decade, making the systems competitive in grid-connected applications.

Degree of Social Acceptability: Excellent. Photovoltaic panels, like low-temperature collectors, can be integrated into building structures in such a way as to be relatively inconspicuous or to provide pleasing architectural effects. Either decentralized (dispersed) or centralized (large) systems can be readily constructed from appropriate numbers of the relatively small power modules.

Environmental Acceptability: Excellent. Some minor environmental problems may exist primarily during manufacture of raw materials such as silicon, cadmium, gallium, selenium, and arsenic.

Institutional Barriers to U.S. Commercialization: Few. With dispersed applications, building codes related to fire and other safety hazards pose some difficulty.

Availability of Financing in the United States: Fair. At current costs, and even with Federal and state tax incentives, photovoltaic systems are largely limited to small systems for electrical needs in remote areas. Financing is generally limited to those systems meeting special requirements of industry, government, commercial business, and persons with above average income. If program cost reduction goals are met, traditional sources of funds for residential and utility construction would become available for photovoltaic power systems.

Availability of Information in the United States: Good. Lifetime, reliability, and cost data are becoming increasingly available through domestic and international tests and applications.

Chapter 5

Biomass Energy Systems

Introduction

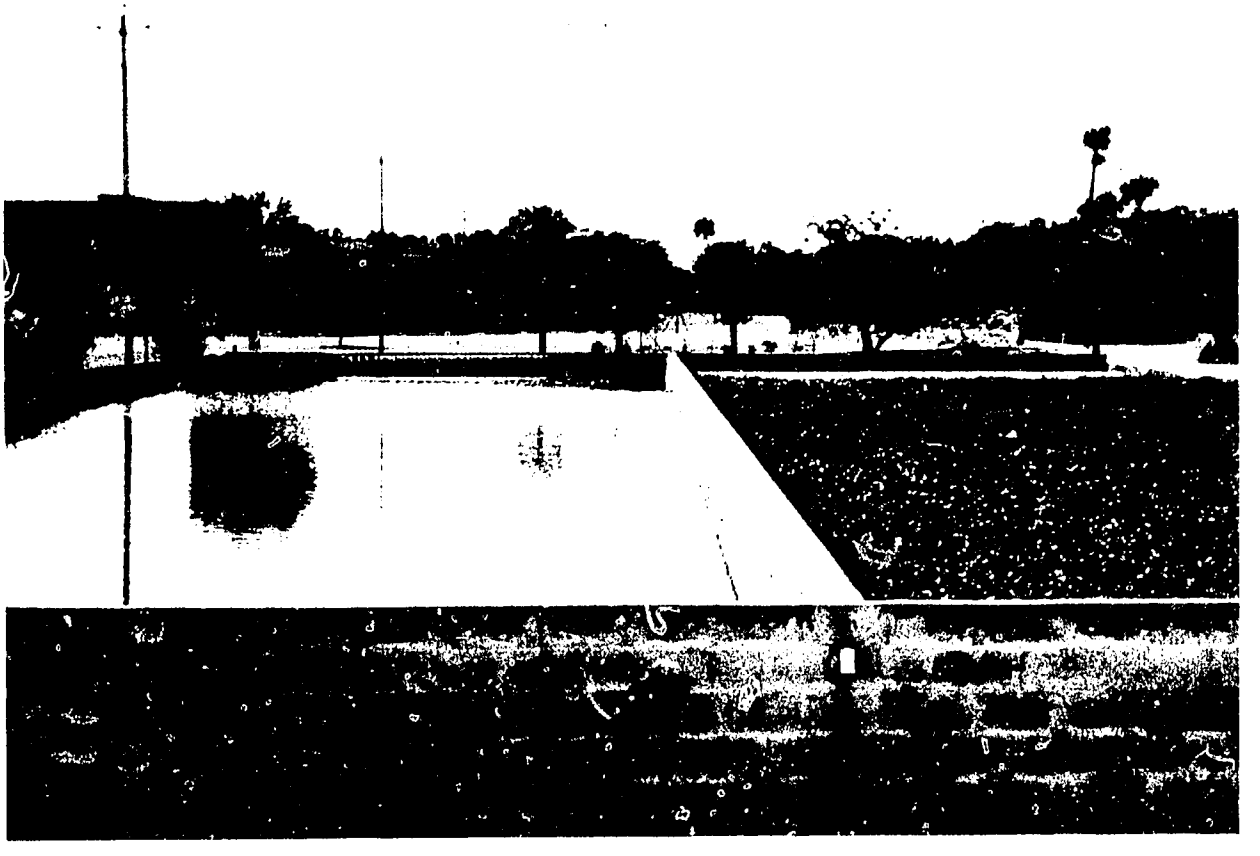
Biomass includes all organic material obtained either directly or indirectly from the growth of plants. Plant growth is produced by the process of photosynthesis, which converts carbon dioxide and water into organic matter and oxygen under the stimulus of light. The continental United States produces a great deal of biomass in all regions except the Southwest. The largest production occurs in the mid-continent (grains and forage crops) and the Southeast and Northwest (wood and forage crops).

Biomass is present in terrestrial and aquatic vegetation, and crops and animal waste products. Biomass includes trees, grasses, grains, sugar crops, water hyacinths, microscopic plants (algae), aquatic plants, and residues from their use. The most common residues include forest, agricultural, animal, municipal, and industrial organic materials.

There are three main approaches to using biomass for energy purposes; each has different economic prospects, energy production potentials, and conversion technologies associated with it. The first involves using biomass residues (the organic material normally left behind from commercial activities). For example, loggers often take only parts of trees, leaving behind many branches, leaves, and sections of trunks. Mills and farms also typically have extensive crop and animal residues. But while residues are sometimes cheap and plentiful at local sites, their energy production potential is limited by the economics of collection and transportation.

The second approach to exploiting the potential of biomass is through "energy farming"—growing plants specifically for their energy content. Some potential energy-farming crops, such as corn and sweet sorghum, are high-yield and energy-rich. Others, such as guayule (a desert bush), produce complex hydrocarbon chemicals that yield oil-like products. Still others are short-rotation tree species, such as the poplar, that can be used as an energy feedstock. The raw materials produced by energy farms generally cost more than biomass residues, but handling and transportation charges can be lower with such crops than with residues (unless the residues are already aggregated). Because energy farms can be located on land of little agricultural value (possibly even on arid land), the potential conflict between fuel production and food production could often be lessened.

The third approach is to cultivate aquatic biomass in both fresh and ocean waters. The aquatic biomass resource is potentially larger than land-based resources, given the competing claims upon land for development, food production, recreation, and other uses.



In Florida, two 0.1-hectare ponds have been constructed for research on aquatic biomass. The testing will focus on conditions affecting the growth of aquatic plants and economical ways of improving this growth.

The United States has extensive biomass resources available to help meet a significant part of its energy needs. Most estimates indicate a potential of 5 to 15 exajoules per year. Biomass currently provides more than 1.5 exajoules of energy — more than 2 percent of the total U.S. energy consumption. The major portion of this energy is used for process heat and electricity generated by the forest products and paper and pulp industries. Recent estimates indicate that the conversion of unused agricultural and forestry residues, and non-commercial timber could provide 6 to 10 percent of the nation's energy needs on a sustained basis. Intensively managed growth of terrestrial and aquatic biomass crops on "energy farms" could increase the biomass contribution to about 16 percent of current U.S. energy needs. The long-term projection for the use of biomass in the United States is at least 10 exajoules annually.

Biomass can be converted into energy or fuels either thermochemically or biochemically. The best-known thermochemical conversion process is direct combustion. Biomass can also be gasified to yield products readily refined into synthetic natural gas, methanol, or ammonia. A third thermochemical conversion process, liquefaction, converts biomass to liquid fuels.

Several biochemical processes convert biomass to gaseous or liquid fuels or produce chemical feedstocks. Biomass can be converted into methane by a process known as anaerobic digestion (or biomethanation). In this process the feedstock (e.g. manure, crop residues, and aquatic biomass) is decomposed by microorganisms in an oxygen-free environment. Another biochemical process, fermentation, converts biomass into alcohol and other chemical or fuel products. Still another process, biophotol-

ysis, uses selected algae to produce hydrogen gas directly in the presence of light.

In 1979, a large slaughtering and packing facility in Florida began converting cattle manure into methane, which now supplies 50 percent of the company's energy needs. Partially funded by the Department of Energy, this one million dollar project also produces protein-rich cattle feed. Despite its experimental nature, the project is expected to pay for itself within less than five years.

These biomass conversion technologies promise to improve the efficiency and versatility with which we can use this energy source. Making greater use of biomass will require people to learn to use it in an environmentally and socially benign way. Potentially, biomass stands to make a large contribution toward meeting U.S. energy needs.

Applications and Status

In homes, biomass (primarily in the form of wood) is used extensively for heating. More than three million U.S. homes (most of them in the Northeast, Southeast, and Northwest) currently use wood to provide some of their space-heating needs. Sales of wood stoves exceeded one million in 1980. Improvements in wood-burning devices, such as fireplace inserts and heaters with controlled combustion, are making wood an increasingly attractive resource.

In commercial buildings, energy derived from biomass is not expected to be widely used, although some uses may prove applicable and economical.

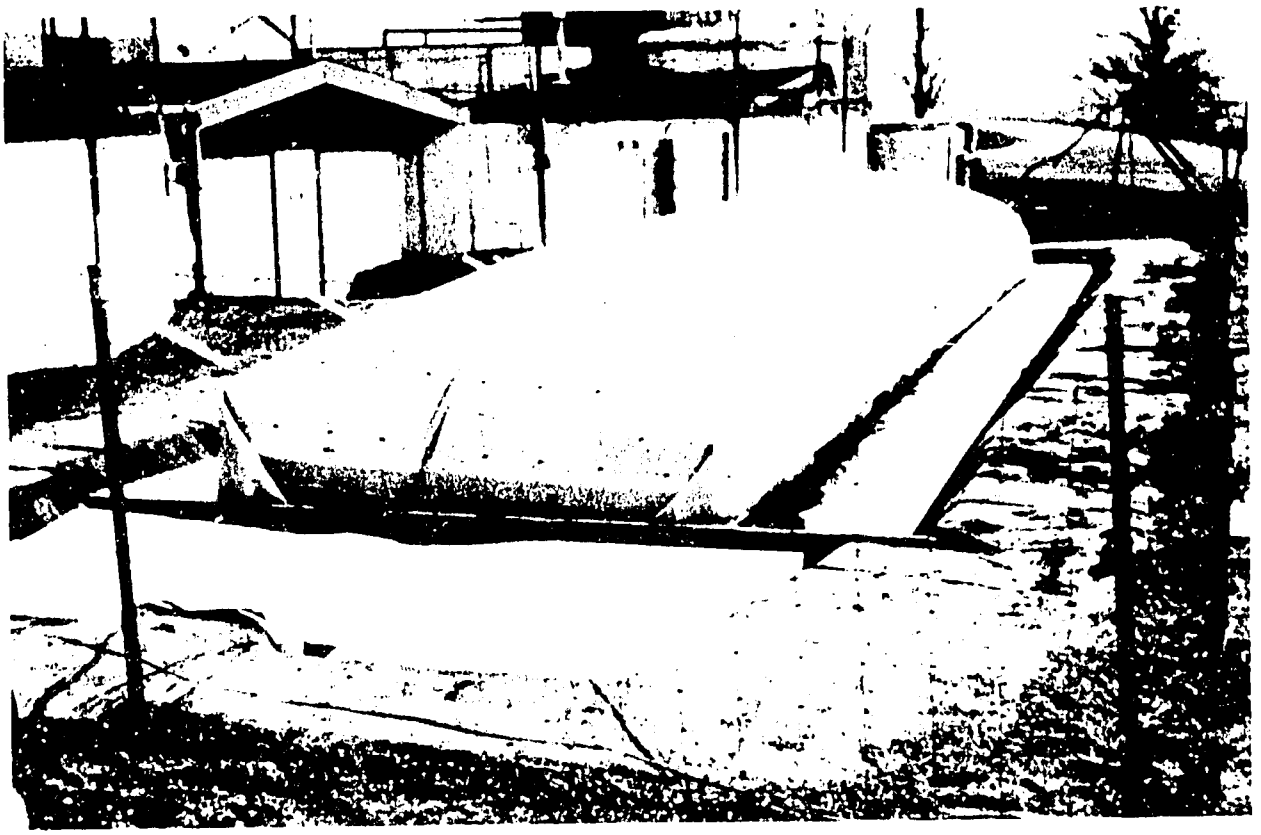
In the winter of 1978-79, a 21,000-square-foot shopping center in Vermont converted its heating system to use wood. This privately funded conversion of the existing boiler cost $40,000. The wood needed for the first winter cost $1,200—compared to $20,000 for fuel oil. This savings indicates that the investment will pay for itself in just over two years.

In the agricultural sector, biomass can provide solid, liquid, or gaseous fuels from readily available sources such as animal waste, crops, and crop residues. Potentially, these could supply much of the energy needed on farms, making them more self-sufficient. Local production of liquid fuels, for example, could ensure the availability of fuel used during planting or harvesting.

Two particularly promising technologies for agricultural use are anaerobic digestion (which converts manure into medium-energy gas) and fermentation (which converts crops and crop residues into liquid fuel). Both technologies are being used extensively in other countries. Alcohol fuel produced on the farm from farm residues and crops could displace petroleum used for transportation and irrigation. Oil from seeds is another promising option, since some seed oils can be used as diesel fuel.

In industry, biomass technologies can use wood to generate process heat or electricity, or biomass can be transformed into gas and fuel oil via gasification or liquefaction. These fuels can be used in existing equipment with only minor modifications.

Forest residues currently supply almost half the electrical and process heat needs of the forest products industry. As the cost of competing fuels increases, such applications will expand and spread to other industries. Even now, the forest products industry uses about 1.5 exajoules per year of biomass, which is by far the largest use of any renewable resource except hydropower.



This anaerobic digestion reactor is used to produce biogas from manure. It is part of a test facility sponsored by the Department of Energy at Cornell University in New York. Both a high-rate digester capable of multiproduct recovery and a low-cost digester suited for use on a typical dairy farm are being developed at Cornell.

A mill located in California uses bark, chips, sawdust, and other waste products to power three 15-megawatt generators that have been working at 70 percent capacity since 1910. The system also produces steam for process heat and disposes of the plant's waste products.

In some industries that have large amounts of a biomass residue, gas produced from biomass is now being used in boilers previously fired by oil or natural gas. Without being upgraded, this gas lowers boiler output by 5 to 10 percent and cannot be economically transported great distances. But, if the price of fuel oil and natural gas increases, industries with access to biomass wastes may turn increasingly to gas from gasifiers.

Another prospect for industry and agriculture is using an upgraded gas (containing about 2 to 3 times the energy of the gas coming from the gasifier either as a fuel or as a "synthesis gas" to produce synthetic natural gas, methanol, or synthetic gasoline. This upgraded gas can be transported economically and substituted for petroleum or natural gas without lowering a boiler's output.

Biomass may be the most useful renewable energy source for replacing fossil fuels in transportation uses. The best known biomass-related liquid fuel is gasohol (a blend of 90 percent gasoline and 10 percent alcohol), which can be used in vehicles with no engine modifications. Ethanol (presently used in gasohol) increases the octane of gasoline, improving engine performance.

With a few modifications, cars with gasoline engines can run well even on pure ethanol, although ethanol yields somewhat lower mileage than gasoline. Another potentially large use of ethanol is as a chemical feedstock for the plastics industry, replacing the ethylene now normally derived from petroleum.

Recent increases in gasoline prices and the elimination of the Federal gasoline tax on gasohol have led to interest in gasohol in the United States. Throughout the nation, many local service stations market gasohol. Production of ethanol for use in automobiles has increased rapidly in the United States.

Over the long term, methanol is perhaps an even more promising fuel than ethanol, since it can be made from a variety of feedstocks other than sugar or starch crops. Its potential use is great in stationary equipment as well as in vehicles, and it may also serve as a feedstock in the production of synthetic gasoline.

Like industries, electric utilities that now burn natural gas or oil could (with only a small reduction in power capability) use a gas derived from biomass. Upgraded, this gas can be transported through existing pipelines—a fact of some importance to natural gas utilities. But apart from isolated experiments, biomass-generated gas is not now used by natural gas utilities.

So far, gas derived from biomass is not the cheapest energy alternative—wood and wood residues are more promising for electricity generation. In particular, wood chips or pellets can be used in some coal-burning utilities with only minor modifications (although woodburning is more efficient in facilities originally designed for that purpose). About five small utilities in the United States currently use wood to generate electric power, and more are considering it as a possibility.

Economics

Since biomass sources, technologies, and applications are varied, so are the costs of using biomass. In general, the capital costs are low compared to other renewable energy technologies and the operating costs are higher.

For the wood-burning stoves used widely in the residential sector, energy costs run about $2-$5 per gigajoule. However, for people who cut wood themselves on their own or on public land, costs are only a few cents per gigajoule. Efficient wood-burning heaters currently cost $300 to $800 installed in the United States.

In agriculture, the cost of biomass depends on which feedstock source is used and on the value of the by-products (such as fertilizer) produced. Biomass is already competitive with fossil fuels for some agricultural applications. For example, manure from 200 dairy cows can yield gas at $3 per gigajoule — comparable to the current price for conventional fuels. Some farmers are also now finding it economical to produce and use alcohol as fuel or to sell it at prices ranging from 35¢ to 50¢ per liter ($1.50 to $2.00 per gallon). Others also rely heavily on ready stocks of wood for home heating. In demonstrations, burning crop residues to provide heat for grain drying has also proved successful.

A North Dakota potato farmer is using his cull (waste) potatoes to make alcohol. The distillation and processing facility, which cost him less than $100,000, will produce 113,000 liters (30,000 gallons) per year from the 3,000,000 pounds of cull potatoes that he would otherwise have discarded. The 190-proof alcohol will cost 15¢ to 20¢ per liter (60¢ to 80¢ per gallon) and will be used in gasohol for normal engines and directly to power converted engines. The residue from the potatoes processed during the alcohol production will be sold for livestock feed.

Over 200 million tons of trash are collected in the United States annually. Biomass-conversion techniques may turn what is now a monumental disposal problem into a valuable resource.

For industrial applications, several biomass sources and technologies are almost cost-competitive. Wood chips or pellets cost $35-$53 per dry metric ton ($32-$48 per dry ton) or $2.00-$3.00 per gigajoule, depending on transportation costs. The price of wood has risen and is likely to continue to rise due to increased demand. The forest products industry uses wood chips extensively, partly because it pays only low transportation charges for wood resources. Gas from biomass residues now costs about $3.50 to $5.50 per gigajoule. (Upgrading the gas adds about $2 per gigajoule to its cost.) In contrast, converting biomass to fuel oil is now expensive: present costs of $8–$9 per gigajoule will probably not fall to $5 per gigajoule until about 1990, by which time new processes should be perfected and the scale of the processing industry increased.

These cost figures are meaningful only when compared to the prices of conventional fuels. For comparison, residual fuel oil, most often used in industrial boilers, now costs $4-$5 per gigajoule. Number two distillate, burned for residential heating and some industrial applications, is now about $40 per barrel, or $7 per gigajoule. In early 1981, natural gas prices were being deregulated in the United States and averaged only about $3-$3.50 per gigajoule (equivalent to a fuel oil price of $18 per barrel of oil). That price will rise as deregulation is completed.

In some transportation uses, too, biomass is now economically viable. The wholesale price of unleaded gasoline, now about 25¢ per liter ($1.00 per gallon), is likely to increase, though at what rate is uncertain. For facilities producing about 100 to 200 million liters (25 to 50 million gallons) of ethanol per year, the selling price is about 45¢ per liter (about $1.80 per gallon). For example, ethanol produced from corn costs an estimated 32¢ per liter ($1.25 per gallon) at corn prices of roughly $2.60 per bushel, if a cost credit for the by-products used as livestock feed is included. These prices may decrease by about 2¢-5¢ per liter (10¢-20¢ per gallon) as fermentation, distillation, and by-product processing techniques improve. On the other hand, the energy content of ethanol is only about 21 megajoules per liter (76 thousand Btu per gallon) and the energy content of methanol is 15 megajoules per liter (55 thousand Btu per gallon), while the energy content of gasoline is 35 megajoules per liter (125 thousand Btu per gallon)—a difference partially offset by a higher octane rating for the alcohols. Further cost reductions are possible if present research improves techniques and technologies for converting lignocellulose (widely available in wood and urban agricultural wastes) to ethanol.

The consumer price of ethanol is reduced by Federal and state tax incentives. A Federal gasoline excise tax exemption for

Gasified biomass can be used in engines. This privately owned vehicle, which recently traveled across the United States, uses wood as a fuel.

gasohol of 1¢ per liter (4¢ per gallon) provides a tax-exempt status for ethanol equivalent to 10¢ per liter (40¢ per gallon). With this and other incentives, ethanol production is currently profitable and gasohol is being sold in the United States in competition with unleaded gasoline. Using current technology, methanol can be produced from wood for about 25¢ per liter ($1.00 per gallon), although this is not being done commercially in the United States since production from natural gas is less expensive.

Natural gas utilities are not likely to use biomass-derived gas for distribution unless research substantially lowers the cost of this resource. In a town in Colorado, the municipal utility plans to use an anaerobic digester to produce gas from manure from nearby feedlots, thus turning an environmental waste-disposal problem into an asset. Increasing numbers of farms are expected to use such systems as successful experience accumulates.

Burning wood for electricity is cost-effective in those electric utilities that are located near a good resource.

Storage and Systems Issues

Biomass systems require no energy storage. In fact, the solar energy stored in biomass can be an excellent back-up for other renewable energy systems.

The utility issues surrounding the use of biomass are much the same as those associated with other types of new and renewable resources. One difference is that fuel transportation costs for scattered, bulky biomass materials are likely to be considerably higher than for concentrated fuels, such as coal. This dictates that, for economic reasons, biomass power facilities be smaller than conventional power plants. These decentralized biomass plants can

lead to cogeneration and total energy systems utilizing the "waste" heat more effectively for space heating, hot water, or co-located industrial processes.

Barriers and Impacts

There are a number of issues that must be resolved if biomass energy is to make a major contribution toward meeting U.S. energy needs.

First, biomass resources are characteristically dispersed, bulky, and variable in quality. This will tend to limit their use to regions where they are locally available or where small plants are adequate.

Second, there are environmental issues associated with both the collection and production of biomass for energy (land mismanagement and soil degradation) and with its use (air quality effects of widespread wood combustion). These environmental issues tend to be similar to those involving fossil fuels but are more controversial than those related to other renewable energy resources.

A third concern with the widespread use of biomass stems from competition for valuable resources such as feed grains, marketable timber, and high quality arable land and water. These factors increase the importance of the use of biomass feedstocks that are waste or residue, or feedstock that can be grown on marginal land or water.

Lastly, anaerobic digestion and biomass fermentation produce by-products that have a high biochemical oxygen demand and may contain unwelcome mineral salts. These by-products must be disposed of or recycled to avoid pollution. This is likely to pose no special problems, however, since the residues have economic value and are thus not likely to be discarded.

Biomass has an advantage over fossil fuels as an energy feedstock because it is relatively environmentally clean. For example, emissions of sulfur oxides and nitrogen oxides, two air pollutants, are significantly less for burning biomass than for burning coal: for sulfur oxides, biomass emissions are up to 70% less; for nitrogen oxides, biomass emissions are up to 60% less. However, of greatest concern are the high particulate emissions, carbon monoxide levels, and possible carcinogenic organic compounds that can occur when wood is burned in residential heating units.

Private Activities

Private biomass-related activities are too extensive to catalog here, though some generalizations are possible. The woodstove industry has grown greatly in the United States during the last decade as Americans have rediscovered the advantages of the fireplace and stove. (The sale of stoves alone now totals about $500 million annually.)

Private activity has also been substantial in the production of ethanol from corn, potatoes, and other crops. Nationwide, an estimated 100 million gallons of fuel-grade ethanol is being produced by hundreds of companies, and plants either under construction or planned will soon expand that figure.

An alcohol distillery built for $15,000 has a capacity to process 12,000 liters (3,000 gallons) weekly using crops grown by co-op members. Each metric ton of corn feedstock yields almost 400 liters (90 gallons) of alcohol. The vats are heated by burning wood waste, old tires, or other inexpensive, easily obtainable fuel.

Several small companies have also ventured into the business of making and selling anaerobic digestion systems. So far, however, their combined sales do not exceed $1 million.

While many new biomass technologies hold great promise, almost all of the 1.5 exajoules that biomass presently contributes to U.S. energy needs is accounted for by the forest products industry, which burns its wastes in boilers. For use in such boilers, the industry developed pellet-making equipment for which a market is now developing. Approximately a dozen plants are now making pelletized biomass from agricultural and forest wastes, and many more are in the planning stage.

Wood used in residential stoves is a rapidly growing source of energy for many U.S. citizens. Used increasingly as backup heating for active and passive solar systems, these stoves are sometimes used for cooking as well.

Government Activities

Federal support for biomass development (including alcohol fuels development) has increased in the budgets of the Departments of Energy and Agriculture. The technologies and processes include direct combustion and gasification and liquefaction of wood and wood residues (as a source of industrial process heat, electricity, and residential heat), the production of ethanol for gasohol, anaerobic digestion of manures to produce gaseous fuel, and direct combustion of agricultural residues for use in agriculture.

However, Federal program efforts in biomass are expected to be directed toward long-range R&D support for advanced technologies to produce alternative fuels and petrochemical substitutes.

Government work on the development of the longer term biomass technologies consists primarily of sponsoring basic energy research and proof-of-concept experiments. Among the biomass technologies expected to contribute to U.S. energy needs after 1990 are energy farms and thermochemical-conversion facilities for producing gas and fuel oil from various cellulosic feed materials (e.g., wood, corn stalks, and municipal organic wastes). Expected to become commercial even later are aquatic energy farms, the cultivation of non-traditional energy-rich plant species, and biophotolysis (direct production of hydrogen) and other advanced conversion technologies.

The activities of the other Federal entities involved with biomass are diverse. The Tennessee Valley Authority, the largest publicly owned utility in the nation, has a no-interest loan program for residential wood stoves in part of its service area. Several states also have active biomass-support programs, especially for ethanol production.

Projections

Although often not considered in U.S. energy accounting, biomass currently provides approximately 1.5 exajoules (2 percent) of the nation's yearly requirements. If the Federal biomass program is successful, another 0.5 to 1.5 exajoules per year will be added before 1985 through the direct combustion of biomass or its conversion into gaseous and alcohol fuels. It is hoped that almost 2 billion liters (500 million gallons) a year of alcohol fuels alone will be produced by 1981, resulting in about 20 billion liters (5 billion gallons) of gasohol. An additional 6 exajoules per year could easily be available before 2000, as biochemical and thermochemical conversion technologies are improved. After 2000, contributions from the innovative land-based and aquatic energy farms now under research might push that total to over 8-10 exajoules per year.

Biomass in Brief

Present State of Development: Combustion - Commercially Ready. The direct combustion of biomass, one of the oldest known renewable energy sources, is in wide use everywhere. ***Production and Conversion - Demonstration Stage.*** The production of methane from anaerobic digesters and ethanol from grain fermentation are becoming commercially ready. Large-scale gasifiers, pyrolytic converters, and fermentation units for lignocellulosic materials need to be demonstrated. Intensive farming of energy crops also needs to be demonstrated.

Resource Availability: Combustion - Excellent. The availability of residues for combustion is not a problem. The resources are regional, and the assurance of long-term supply may be a concern in utility and industrial applications. ***Production and Conversion - Excellent.*** The biomass resources can be produced on marginal lands where they are not expected to compete with the need for food production. Availability of water may be a concern.

Fossil Fuel Displacement Potential: Combustion - Very Good. Availability of wood and agricultural residues, albeit regional, offer significant fossil fuel displacement potential in the near term. ***Production and Conversion - Excellent.*** Land-based and aquatic production and conversion of biomass to fuels may provide the largest share of U.S. energy needs from among the renewable energy resources.

Cost-Competitiveness with Fossil Fuel: Combustion - Excellent. Although increasing, wood prices are still competitive with fossil fuel prices. For many large users, the residues are waste products and hence cheap. ***Production and Conversion - Good.*** Anaerobic digesters appear to be most competitive, with gasifiers next. The production of liquid fuels could be competitive by 1990 with fossil fuels. Alcohol fuels from grain are commercially available as a result of Federal tax incentives.

Degree of Social Acceptability: Combustion - Excellent. Wood combustion is aesthetically pleasing in home-heating applications. Combustion of wood residues in industrial applications has been an accepted practice. ***Production and Conversion - Excellent.*** Biomass production is not expected to compete with food production for land in the United States and hence, social acceptance of this renewable option will not be a problem if the public is adequately informed.

Environmental Acceptability: Combustion - Very Good. Wood combustion does not release significant amounts of sulfur oxides; but carbon monoxide, organic compounds, and particulates may pose some problem with residential wood combus-

Ethanol for use in the transportation sector is one of the fastest growing biomass technologies. Sold in many U.S. gasoline stations as a gasoline-ethanol mixture called gasohol, the ethanol is generally produced from corn, although other materials also are being used.

tion. ***Production and Conversion - Good.*** Issues such as land use, depletion of soil nutrients, soil erosion, and air pollution may need to be resolved for large-scale use. The environmental acceptability of biomass energy farming is very site-specific.

Institutional Barriers to U.S. Commercialization: Combustion - Few. Safety or environmental regulations may inhibit use of biomass combustion applications. Systems for collecting and transporting residues need to be developed for dispersed applications. ***Production and Conversion - Few.*** An industrial base for production, harvesting, collection, conversion, and distribution needs to be developed, but no major potential barriers are anticipated.

Availability of Financing in the United States: Combustion - Excellent. Combustion of residues in forest products industry is already commercial. Other industrial and utility applications are economically favorable in regions with an adequate wood supply. The use of wood will be enhanced by decontrol of oil and gas prices. ***Production and Conversion - Fair.*** The biomass production and conversion technologies need to be demonstrated prior to widespread use. However, anaerobic digesters and ethanol production from grain are attracting some capital investment.

Availability of Information in the United States: Combustion - Very Good. Data on regional wood resources are available through state and local organizations. ***Production and Conversion - Fair.*** Technical data in an operational environment are not currently available. Information on anaerobic digesters and ethanol production is available through various information centers.

Chapter 6 Wind Energy Systems

Introduction

Wind energy is the kinetic energy associated with movement of large masses of air resulting from uneven heating of the atmosphere by the sun. Wind energy conversion systems convert this kinetic energy to more useful forms of power. Overall, a moderately windy site (average wind speeds of the order of 7 meters per second, or about 15 miles per hour) has an annual available energy potential comparable to that of a sunny site. Although the wind resource at a given location can vary a great deal with time (including no wind), it can be available continuously throughout a 24-hour day, and even for much longer periods, in contrast to the diurnal availability of direct solar radiation. This energy availability is important to the design of systems and the cost of delivered energy.

The most common wind turbine system involves a tower-mounted, multi-bladed rotor facing into the wind, rotating around a horizontal axis (with the blades perpendicular to the earth's surface), and turning an electric generator or a mechanical gearbox connected to its axis. The most common modern, high-performance rotor configuration is based upon lift-type blades, much like a two-bladed airplane propeller, as compared with the popular multi-bladed, fan-type blades used in many rural, water-pumping systems. Modern wind turbine systems can be designed to convert as much as 40 to 50 percent of the kinetic energy flowing through the swept-area of the rotor blades into rotary power.

Several other wind machine designs are also being developed in the United States. The most promising is the Darrieus vertical-axis wind turbine which uses "egg-beater" style blades. A vertical-axis machine could potentially save on construction and maintenance costs. Both horizontal and vertical-axis wind turbine systems are being sold commercially in the United States.

Wind energy systems have been used for irrigation and milling since at least the second century B.C. Since 1900, they have also been used to generate electric power. With the notable exception of the 1.25-megawatt wind turbine located at Grandpa's Knob, Vermont, which was the largest wind machine ever built until 1979, most wind systems have been in the range of a few kilowatts to a few hundred kilowatts in peak power output. Although a number of intermediate-sized units (measured in the hundreds of kilowatts) were also tested in Europe from the 1930s through the 1950s, wind power's appeal faded after World War II. But recent increases in the price of conventional energy have again focused attention on the wind as an important resource.

An Iowa farmer bought two small wind-powered generators in the 1920s. Although he is a heavy consumer of electricity in his machine shop and home, he has yet to pay a cent to a utility. For storage he uses three banks of batteries manufactured over 75 years ago. These provide him with electricity for four or five days at a time when there is no wind.

This two-megawatt wind turbine in Boone, North Carolina, has a blade diameter of approximately 60 meters. Although its rated power is developed at wind speeds of greater than 40 kilometers per hour, it can operate at wind speeds below 20 kilometers per hour.

Electric power generation is probably the principal application for wind systems in the United States, but water pumping and mechanical applications are also practical and efficient. In the United States, smaller electrical systems (1-100 kilowatts) are expected to be employed on site for residential and farm uses; intermediate-scale systems (100 kilowatts-1 megawatt) for large farms, irrigation systems, small utilities, and remote communities; and, large systems (greater than 1 megawatt) for electric utility and industrial uses. Machine size is one determinant of these user classes: the rotors of a small machine are only a few meters in diameter, whereas the rotors of a wind turbine rated at 2 megawatts may be about 100 meters in diameter. Siting is an equally important consideration in planning a wind system, since performance and economics are closely related to the local wind speed.

There are two principal types of wind machines. Horizontal axis systems, which often resemble airplane propellers mounted on towers, are usually yawed to face into the wind. Vertical axis machines, some of whose rotors look like egg beaters, operate with the wind coming from any direction without movement of their axis of rotation.

Increasingly, wind power is viewed as economical in the numerous locations where the average wind speed is high. Most wind systems and components can be built from readily available materials and can be used in either centralized or decentralized applications. The price of wind power is expected to fall as advances are made and wind machines are mass produced.

Applications and Status

Wind systems should have unobstructed access to the wind coming from any direction to obtain the lowest-cost power over their average lifetime of 20 years, or more. For that reason, it is expected that their early economical applications will be primarily in rural or semi-rural areas. The rural residential market for small wind systems (2-10 kilowatts) is potentially large. In the United States, six million wind-powered water pumps operated at the turn of the century. While the federally subsidized electrification of rural America by means of central power plants and grids eliminated this market for wind machines during the 1930s, the rising cost of electricity from these same grids is now making wind machines more and more attractive to rural users. At the same time, utility planners are considering large wind turbine systems for additional grid generation capacity.

Residential wind-powered generators will probably be used in much the same manner as photovoltaic systems. A wind system could, for example, provide up to 50 percent of a home's energy needs, with back-up power coming from public utilities. The question of pricing this back-up power has yet to be resolved, although the Public Utility Regulatory Policies Act (PURPA) has established the utility's responsibility to provide back-up energy at the standard rate (unless it can prove to the State Regulatory Commission that it is losing money by doing this) as well as to purchase excess power from the small power producer at fair prices.

Where back-up power from a utility is not available, other approaches to using wind power are being considered. One is to incorporate energy storage into the system. Another is to use electricity only when the wind energy is available. However, using wind power as it is available would require a life-style change for most power users. Remote wind systems in the United States would need to include some type of storage system, which would increase the system and power costs.

Agriculture provides a potentially excellent market for small- and medium-sized wind machines. Wind power can be used directly for mechanical processes, although these applications might require changes in the power-using equipment. With the addition of energy storage, wind-powered generators can provide electricity for many agricultural uses.

A resident of New Jersey had a 45-kilowatt wind generator installed on his 29-acre farm. The system, which cost $35,000, will produce about $6,000 worth of electricity each year at current prices. Thus, it will pay for itself within the first eight years of an expected 25- to 30-year lifetime.

Another major application for wind energy is the electric utility industry. Utility interest depends on many factors. These include the size of the wind energy resource, the availability of storage capacity and peak load generation capacity, and the daily and seasonal power demands in a given region. Without storage, approximately 20,000 wind machines rated at 1.5 megawatts each and distributed over a variety of wind conditions will be needed to displace one exajoule per year of fuel. While the logistics of this much construction are formidable, completing a project of this magnitude is well within the capability of a utility industry that has constructed 300,000 transmission towers (similar in design to wind energy towers) in the last 15 years and an aerospace industry that has built tens of thousands of aircraft over shorter periods of time.

Today, most sales of wind machines are to rural residences and farms. The total number of new machines sold since the renewed interest in wind energy began in the early 1970s is estimated to be only a few thousand in these two sectors. However, interest and sales are rising rapidly each year as improved machines are being marketed. Over 50 utilities have research projects in wind energy, and a few have incorporated wind machines into their electricity-generation systems. For example, the Southern California Edison Company has installed a 3.5-megawatt horizontal-axis system and a 500-kilowatt vertical-axis system at its own expense. Similarly, Hawaiian Electric has contracted with a private firm to supply the utility with 80 megawatts of wind-generated power, and Pacific Gas and Electric in California is interested in buying about 100 megawatts from another firm.

Wind energy has found only a few uses in commercial or industrial establishments because business and industry tend to be located primarily in urban areas where

buildings may block the wind, where institutional problems exist, and where utility power is readily available.

A small oil producer in a remote area of Wyoming is now using a wind machine to pump crude oil from a well. The wind system is so much cheaper than the propane-powered pump he had previously used that he predicts a one-year payback period for the $2,500 machine.

Interest in wind-assisted freight ships and in wind-generated electricity for electric or hybrid vehicles is rising. Some experimental ships incorporating sails to augment engine propulsion systems are being tested in commercial operations.

Modern wind generators are much larger and designed to work at higher speeds than the wind pumps that have been in use for years. However, the new machines, like their forerunners, must be raised well above ground level and must contain mechanisms for converting the wind's energy to mechanical or electrical energy. This 200-kilowatt machine in New Mexico, has blades of 40 meters in diameter on a tower more than 30 meters high. It has operated successfully since 1978.

Economics

The economics of producing power from wind systems depends strongly upon the magnitude of the wind resource. An average annual wind speed of 24 kilometers per hour compared to 19 kilometers per hour can reduce power costs by about one-half. Some systems on the best sites are projected to cost about $600 per kilowatt, and to produce energy at 3¢-4¢ per kilowatt-hour. Such systems can be competitive with electricity from non-renewable sources in most areas of the United States.

Wind machines of all sizes are expected to become fully cost-competitive with non-renewable power systems in the mid-1980s, particularly in remote areas. Improved technology and more efficient production are expected to reduce the present capital costs of wind systems by at least one-half in the 1980s. The energy cost of 3¢-4¢ per kilowatt-hour, reported now for a few high-wind sites, should become commonplace for advanced large machines.

A word of caution is in order here regarding the capital costs of wind machines. Wind turbines do not operate at full capacity all the time. At very windy sites, they may operate at 40 to 50 percent of rated capacity, but 25 to 35 percent is more typical. (For comparison, a power plant based on non-renewable fuels may operate 50 to 75 percent of the time.) On the other hand, capital cost is by far the greatest determinant of the cost of energy obtained from a wind turbine, while conventional

plants are subject to both fuel costs and capital costs. Thus, comparing the cost of energy on a life-cycle basis is more favorable for renewable power systems compared to non-renewable power systems.

Several Federal actions strongly affect the economics of wind machines for non-utility use. Residential wind machine owners receive a 40 percent Federal income tax credit (plus an additional credit in some states), while businesses can get an investment tax credit of 25 percent (an additional 15 percent more than the usual 10 percent investment tax credit) for investing in wind machines. Moreover, under the Public Utility Regulatory Policies Act (PURPA), any wind machine owner can sell excess power to the local utility at a fair rate, as the private companies selling wind-generated power to Hawaiian Electric and Pacific Gas and Electric are now doing.

Storage and Other Systems Issues

The electric-storage methods and issues discussed in Chapter 4 with respect to photovoltaics also bear directly on large-scale wind use. However, wind devices and photovoltaics differ in several ways. First, individual wind generators usually operate more hours per year than photovoltaic units will, because wind can be available 24 hours per day whereas direct solar radiation is available only during daylight hours. Because of the variety of wind conditions within any utility's service area, large numbers of wind generators distributed over a utility service area are expected to have a more constant power output than would the same number at a single site. Taken together, these characteristics of wind systems reduce, but do not eliminate, the need for utility energy storage and peak power capacity to backup the wind system. A number of analytical studies have been performed to develop a methodology for assigning potential capacity credit to wind systems in a large utility grid system.

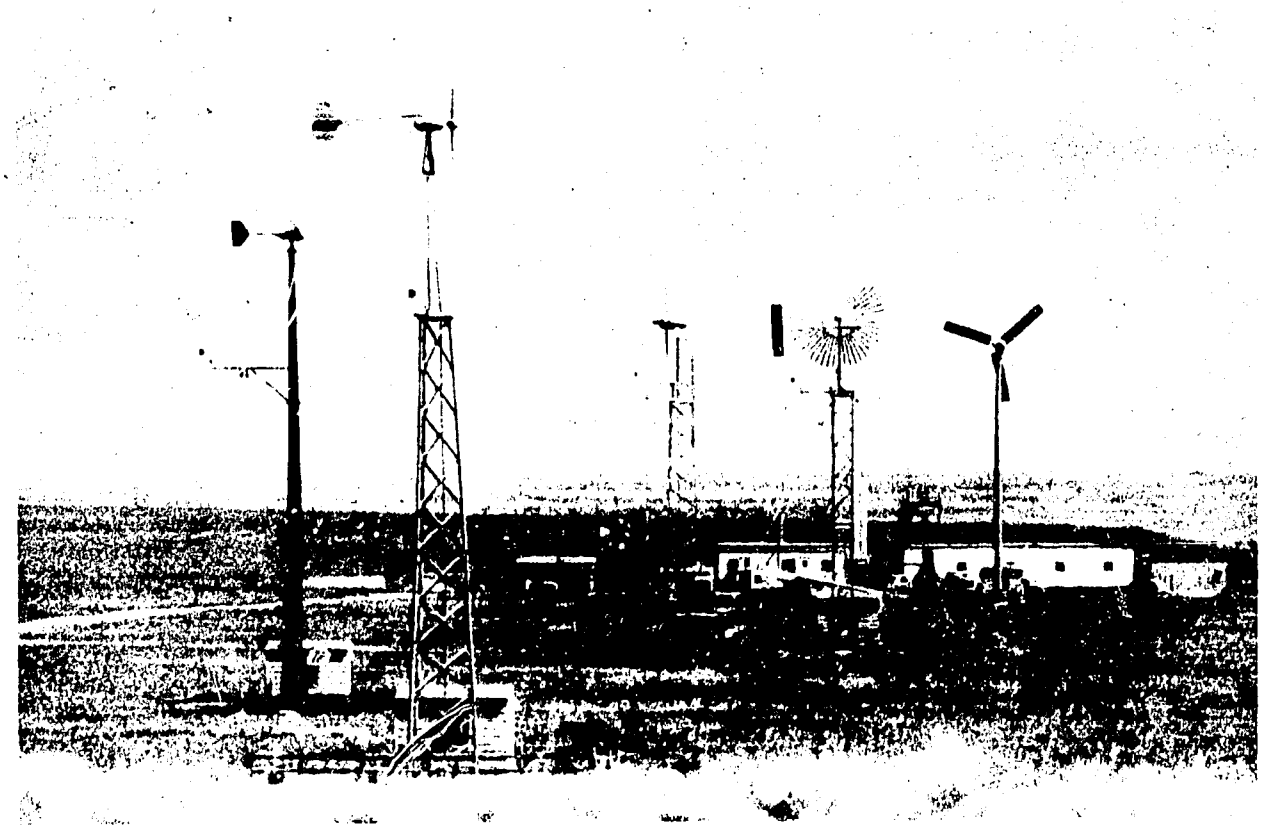
Another issue arises from the nature of the wind resource. The energy content of the wind fluctuates more quickly and more widely than the power output of many other renewable resources for two reasons. First, the wind can gust and then calm down dramatically and quickly. Second, the power density of the wind is proportional to the cube of the wind speed: wind with a speed of 20 kilometers per hour has eight times as much power as wind with a speed of 10 kilometers per hour.

The intermittent nature of wind poses new operational problems for wind power users, and for utilities. To reduce this problem, wind machines can, for example, be coupled with pumped-water systems such as reservoirs.

Barriers and Impacts

Other barriers besides initial cost of installed systems are impeding the rapid commercialization of wind machines. One is a lack of practical experience with the new wind machines. Information about equipment reliability and lifetime is also scarce. The potential customer, whether an individual or a utility, needs more detailed data on performance and cost. Utilities have little hard information on the effects of interconnecting wind machines with their electricity grid. An experiment with three adjacent large wind turbines will begin operation in 1981 to obtain this vital information. At the same time, many wind machine manufacturers are still perfecting their machines, and some installed experimental systems have not worked as well as predicted. Overall, these problems are to be expected and should disappear as the industry matures.

Several environmental issues have been raised in conjunction with wind machines. One is the fear that the machines could throw rotor blades or otherwise come apart. (To reduce the likelihood of this



At Rocky Flats in Colorado, a federally-funded project tests and monitors the performance of commercially available small wind energy conversion systems. Research also is being done at the 18 test pads to improve the efficiency and reliability of these machines. Almost 30 different machines have been tested so far.

problem occurring, manufacturers are urged to field test their wind machines.) Large systems with metal blades can cause electromagnetic interference and can disturb television reception. One large horizontal-axis machine generated vibrations in buildings within several miles of the machine. In general, remedial actions in changing operating conditions or using insulator rotor materials instead of metal have essentially solved the major problems.

Some concerns about wind power involve the aesthetics of large numbers of wind machines in a local area. Other concerns are legal, such as zoning and liability questions.

The availability of capital for investment in wind systems raises still another set of issues. Private capital for manufacturers has been available, but it will remain limited until the market is better established. For now, this barrier is being addressed directly by Federal personal income and business investment tax credits and by the PURPA legislation.

Private Activities

The private sector is very active in wind energy development. In the United States, about 35 concerns are manufacturing small-scale wind electric systems, six are producing medium-scale electric systems, and four are fabricating large-scale electric systems. In addition, four companies are producing mechanical wind machines, largely for water pumping. Sales are small

although rapidly growing: about $10-$15 million in 1980 sales of small and large machines totaling about 5 megawatts of capacity. More than 90 private groups are involved in wind energy research.

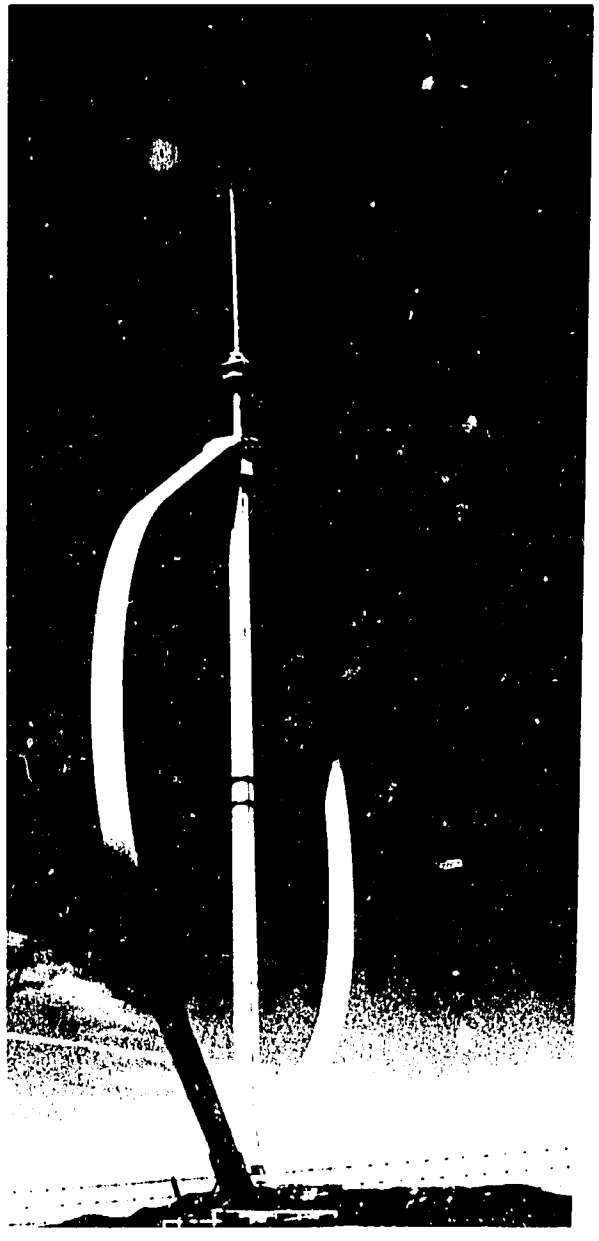
Many small, enterprising companies with innovative ideas have been active in the small wind system market during the past ten years. For example, one company's first effort was to have its employees travel the back roads of the midwestern United States buying windmills left over from the 1930s. The company then refurbished, improved, and resold the machines.

During the past five years, a large number of companies have joined the wind energy business. Large aerospace companies, for instance, have been participating extensively in the Federal wind program, as well as investing their own funds for research and product development. The "wind farm" companies—those planning to erect clusters of wind machines at particularly good sites and selling the energy to utilities—also may become an important part of the industry.

Government Activities

The Federal Government has spent more than one hundred million dollars since 1975 to develop wind energy technology, mostly for horizontal-axis machines. About 60 percent of the 1981 wind budget is earmarked to engineering development and wind-machine testing. Funds also supported research and analysis, technology development, and the study of wind characteristics.

Although the Department of Energy wind program involves all sizes of wind machines, a major percentage of the funds is used to develop larger machines because they are inherently more expensive to design and test and thus a high risk venture



Darrius vertical axis wind turbines with rotor diameters of 2.5 and 17 meters have been tested at Sandia Laboratories in New Mexico. First-generation industrial systems are being analyzed and design improvements investigated.

for private companies. Managed by the National Aeronautics and Space Administration, the large-machine program has focused on erecting progressively larger wind machines. Under its auspices, four 200-kilowatt systems are being tested: one in New Mexico has operated more than one year; one off the New England coast has

supplied up to 50 percent of an island's power on windy, winter nights. A 2-megawatt turbine recently brought into operation in North Carolina is the world's largest (its rotor is 68 meters in diameter). Three even larger machines with 90-meter diameters and ratings of 2.5 megawatts are scheduled to be operated as a three-machine cluster starting in 1981 in the State of Washington. These latest machines are expected to be cost-competitive for utility applications by the mid-1980s. In all, over 10 megawatts of wind system capacity will have been installed by the Department of Energy by late 1981.

The Department of Energy's small wind machine program has been testing commercially available small machines. A test center in Colorado can test up to 18 small systems simultaneously. Federally funded Sandia National Laboratories in New Mexico has primary responsibility for developing vertical-axis advanced wind machines. The Solar Energy Research Institute in Colorado manages the R&D activities in the wind program.

Other agencies are also active in wind system development and commercialization. The Department of Agriculture has a major responsibility for developing small machines for rural use. The Water and Power Resources Service has initiated a large project in Wyoming that couples wind and hydropower resources.

Projections

According to a published study by the Domestic Policy Review Panel for Solar Energy in 1979, wind power applications in the year 2000 could provide up to 1.7 exajoules or some 2 percent of our total energy demand by the turn of the century. In both the public and private sectors, wind energy is rapidly being developed and commercialized. Wind energy is already cost-competitive in many specialized applications. Stimulated by economies resulting from mass production, by the manufacture of larger machines, and by technological advances that contribute to greater reliability, the wind industry could well enjoy a boom in the future.

Wind Energy Systems in Brief

Present State of Development: Demonstration Stage. Small systems are available commercially. Intermediate and large wind machines are being demonstrated at various sites.

Resource Availability: Excellent. Alternative blade materials that are cheaper, easier to fabricate, and equivalent or better in performance than steel, aluminum, or wood are being investigated. All materials currently used to manufacture wind machines are available in required quantities for commercialization.

Fossil Fuel Displacement Potential: Good. The wind energy resource is regional and site specific. Nevertheless, substantial wind energy potential exists in regions, such as the Northeast, where energy needs are acute.

Cost-Competitiveness with Fossil Fuel: Very Good. Wind machines are expected to be competitive with oil for generation of electricity by 1985 or earlier. Small wind machines are economical in farm and rural applications. With the availability of systems-wide storage for utilities, wind machines would have substantial market penetration by the 1990s.

Degree of Social Acceptability: Very Good. The wind machines for electricity generation will be located away from urban areas, and thus the potential problems of noise and television interference will be

negligible. The same is true for deployment of small wind machines in rural or remote areas. The use of wind machines in urban areas is expected to be limited due to wind obstructions, noise, television interference, and aesthetic problems.

Environmental Acceptability: Excellent. The impact of wind machines on water and air quality is expected to be minimal, with harm to wildlife being negligible.

Institutional Barriers to U.S. Commercialization: Few. Interest of utilities in wind machines as a power resource is growing. Regulatory constraints for utility use are expected to be minimal. The issue for the use of wind machines by dispersed users, the requirements for back-up power and sell-back of excess power to utilities is being resolved favorably through PURPA regulations and Public Utility Commission decisions.

Availability of Financing in the United States: Very Good. Access to capital for small and large machines should not be difficult due to cost-attractiveness. Mass production and efficiency improvements should lower costs substantially.

Availability of Information in the United States: Very Good. The small machines are commercially available and have been performance-tested. Several large machines are being placed in utility grid operation and the data are expected to be available to decision makers in industry.

Chapter 7
Ocean Systems

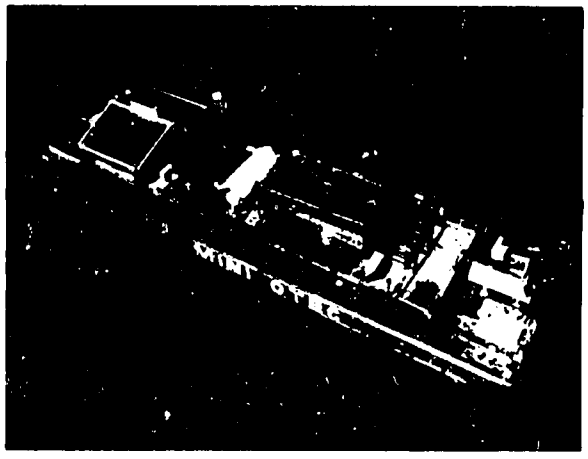
Introduction

Energy conversion systems for utilizing four different ocean energy resources are being developed in the United States. Under development are systems for ocean thermal energy conversion (OTEC) and for harnessing wave energy, ocean currents, and salinity gradients. The OTEC concept is based upon the exploitation of the temperature differences between warm surface water and cold subsurface water (1000 meters or more in depth) to operate a heat cycle (Rankine cycle) that generates electricity. This temperature difference always exists in the ocean, although its magnitude depends on location, ocean depth, and seasonal weather changes. Two technical approaches are the "closed cycle," which is based on evaporation and condensation of a separate working fluid with a low boiling point (such as ammonia or propane) in a closed loop; and the "open cycle," in which seawater is used as the working fluid in a once-through fluid system. Components and systems based on the closed-cycle approach are being developed most rapidly and are nearest to commercial availability.

Although the OTEC technology is receiving the bulk of the funding in the U.S. ocean systems program, R&D is under way on technologies for the extraction of kinetic energy from waves and currents and for conversion of energy from salinity gradients. Salinity gradients arise from differences in salt content of water in a local region; e.g., fresh river water flowing into ocean water, or heavily-salted water (salt lakes) adjacent to less-heavily salted water. Power from salinity gradients is generated from differences in chemical energy potentials of two solutions of different salinity and the use of physical (osmosis) and chemical (reverse electrodialysis) methods to generate electric potential and currents. Wave energy power systems extract mechanical energy from naturally occurring ocean waves and convert this energy into electricity by means of a wide range of devices (surface followers, pressure-activated devices, and wave-focusing devices). Ocean current conversion involves use of large, submerged hydroturbines anchored in the path of a strong ocean current and connected to an electric generator. Systems based on wave energy, ocean currents, and salinity gradients are all in early stages of development.

Ocean thermal power systems can provide continuous power based upon the quantities of stored warm (surface) and cold (deep) ocean water resources, which are essentially independent of daily variations in solar radiation. This natural storage feature lends itself to ocean thermal power systems having the valuable quality of continuous power production. (Hydropower, solar ponds, and biomass systems are the only other renewable energy sources having natural storage features.) Moreover, the resource potential is large; tens, if not hundreds, of exajoules are available annually in the vicinity of the United States alone. Internationally, ocean thermal energy is one of the few available energy sources that

could satisfy all of the world's needs in the 21st century. A huge resource is present in much of the tropical ocean areas. The principal drawback of ocean systems is their preliminary stage of development. Although recent experiments demonstrate the technical feasibility and improved performance of components of ocean thermal systems, their economic feasibility remains to be established.



Mini-OTEC is an experimental 50-kilowatt closed-cycle OTEC system that began operating in August 1979. It was funded jointly by a group of private companies and the State of Hawaii. The heart of the system, a polyethylene cold-water pipe, is 500 meters long and 70 centimeters in diameter. This pipe is anchored 90 meters from the sea floor and is supported by a buoy on the surface.

As envisioned in the United States, commercial OTEC plants are expected to be most economical in the 100- to 500-megawatt range. However, smaller plants (5- to 100-megawatt) may become commercially viable for certain applications. Small plants for island site deployment are, in fact, being designed by engineers in the United States and other countries.

Use of the oceans as a source for renewable energy has a century-long history. OTEC was first conceived in the late nineteenth century, and a prototype open-cycle power plant was built on the coast of Cuba around 1930. This facility worked, but the economics were not acceptable then because of the low cost and availability of competing fuels, largely coal and oil. In the early 1950s, an OTEC facility was designed by French engineers for operation off the Ivory Coast in Africa, but it was not built. In 1972, the United States government began development of the OTEC option.

Currents and tides were first used to produce energy in this country in the eighteenth century in New England. With the timed opening and shutting of sluice grates, tides produced an estimated 50 horsepower at each mill. Interest is now picking up again. Technology is already available for harnessing tides commercially. Unfortunately, there are not many locations where large tidal changes, desirable shore and near-shore characteristics, proximity to markets, and an absence of adverse environmental considerations combine to allow an economical tidal power system. The resource is modest in terms of practical and available sites.

Applications and Status

OTEC systems work most economically where ocean temperature differences are the largest. The best commercial sites are located in tropic and subtropic ocean areas having deep, cold water, predictable currents, large temperature differences, and relatively storm-free weather patterns. These sites are generally far from populated land areas. However, the ocean energy resources adjacent to the United States mainland are significant (e.g., the Gulf of Mexico and the Gulf Stream off the U.S. Eastern Coast), and there are many locations near islands where good thermal differences are present close to land (e.g., Puerto Rico, Virgin Islands, Hawaii, and Guam). Thus, the OTEC program is developing technology and systems aimed at floating plants in tropical and subtropical waters and near-shore and onshore plants for deep-water sites adjacent to the U.S. mainland, islands, and territories.

There are two key applications of OTEC technology. The first is to produce baseload electricity offshore, then transmit it via a submarine electrical cable to utilities, industries, and other on-shore users. The second is to manufacture energy-intensive products such as hydrogen, ammonia, and aluminum aboard cruising OTEC "plantships." (Hydrogen would be derived from the electrolysis of water; nitrogen would be obtained from air liquefaction and combined with hydrogen to synthesize ammonia.) Hydrogen or ammonia can be transported for subsequent production of electricity using fuel cells. There is an increasing world demand for ammonia as a fertilizer, and both hydrogen and ammonia will find applications as fuels and chemical feedstocks. Both floating plants near-shore (up to about 200 miles) and land-based plants are under consideration in the ocean thermal program planning for the mid-to-late 1980s.

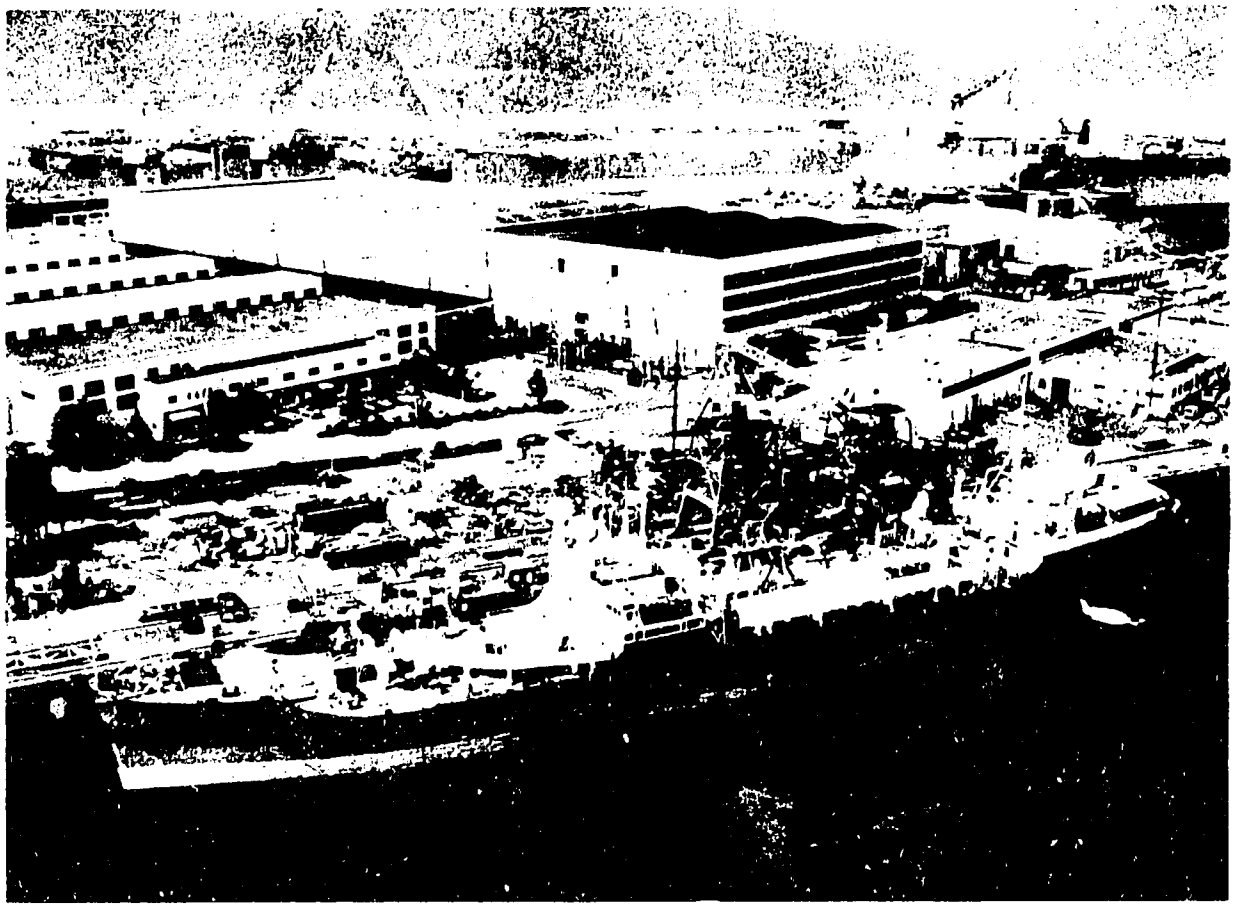
For cable-connected applications, the best U.S. OTEC sites appear to be in Hawaii, Puerto Rico, the Virgin Islands, Guam, and the Gulf Coast states. The islands are choice locations, since the available ocean thermal differences are considerably greater there than near the Gulf Coast and since the appropriate ocean thermal resource is often within one to nine kilometers from shore so that relatively short underwater electrical transmission cables are necessary. (Along the Gulf Coast, the suitable resource is more than 100 kilometers from land.) In some cases, the OTEC plant can be land-based, which may reduce development risks and further improve OTEC's economics. A key factor in the early commercial development of island-based OTEC power plants is that the islands now get almost all of their power from expensive imported oil. Thus, OTEC-produced baseload power may well be economical for the islands by the early 1990s.

Economics

Among the ocean energy options, OTEC is technically ready and a 10- to 40-megawatt pilot plant could be demonstrated in the mid-1980s. Mature, cable-connected, closed-cycle OTEC plants are being projected in OTEC system application studies to become commercially available at a capital cost ranging from $2500 to $3000 per kilowatt (in 1980 dollars) by the late 1980s. Although baseload OTEC plants might be 50 to 100 percent higher in installed system capital costs per kilowatt of power capacity compared to coal or nuclear power plants, they are not subject to escalating fuel costs throughout their operative life, unlike non-renewable power systems in which fuel costs can become the dominant factor in the future price of generated power. Hence, even early commercial OTEC plants are expected to be competitive with existing oil plants when life-cycle costs are considered, and advanced plants may be competitive with coal-fired plants.

OTEC plantships producing energy-intensive products far from shore can also be economical because of savings in mooring and cable costs, because of the ability to work with larger temperature differences, and because ocean transportation costs are low. However, OTEC electrical plant designs for U.S. islands are still expected to be viable earlier because of these islands' present high cost of generating electricity.

Technologies for utilizing ocean currents, wave, and salinity gradients are in early stages of development, and convincing economic projections cannot yet be made. It seems apparent, however, that a major factor in the cost of energy from ocean current and wave systems will be mooring costs.



OTEC-1, a converted U.S. Navy ship, is the first major engineering research facility flexible enough to test various OTEC components. The facility is located off the Kona Coast of Hawaii, where a 20° C temperature difference exists in water that is 400 meters deep. Initial tests began in late 1980.

Storage and Other Systems Issues

A major advantage of ocean thermal energy systems is their ability to supply power continuously. Storage is not required, and utilities can utilize the AC power from the cable directly to a central electric grid. However, the use of wave and tidal power would necessitate storage. Tidal power is unique in one regard: because of its cyclical pattern, it could be integrated into a utility grid without storage if the tidal system were small relative to the rest of the system.

Barriers and Impacts

The key barriers to the commercial viability of ocean energy systems are perceived technical and economic risks. Before industry, investors, and utilities will become convinced of ocean energy's economic soundness, they will need to see encouraging performance and cost data developed from the operations of a pilot plant. In the case of OTEC, a 10- to 40-megawatt closed-cycle plant is expected to provide that information. Insofar as the other ocean energy options are being

investigated, it is premature to gauge their commercial prospects pending further research and development.

Perceived environmental attributes of OTEC are that it will be acceptable and probably preferred in comparison to non-renewable baseload options. Some concern has been expressed about the possible impacts of the biocides that may be used to control biofouling, and about the accidental leakage of harmful working fluids. It has also been suggested that OTEC plants could significantly lower surface water temperatures over large ocean areas and give rise to perceptible changes in world weather patterns. Though studies of this type of impact are preliminary in nature, they do not indicate a significant problem. This is because economic plant operation requires rejected cold- and warm-water streams to be channeled away from the plant to avoid depressing surface temperatures and thus the temperature difference on which OTEC performance depends. So far, analysis and testing of environmental impacts reveal no cause for regarding commercial OTEC plants with apprehension.

OTEC may face unique legal questions because some plants are likely to be located in offshore areas that are subject to overlapping levels of jurisdiction, including international, national, state, and local. Additional questions concern the availability of the resource, its ownership, and the resolution of conflicting uses of the sea, although these were largely resolved by recent legislation.

The supply of titanium has been identified as a possible material problem for closed-cycle OTEC systems. Titanium is the principal candidate material for the very large warm-water and cold-water heat exchangers required in these systems because it would avoid seawater corrosion problems. Ample supplies of U.S. titanium ores are believed to be available at competitive cost.

construction of conventional power plants. Others include marine and offshore oil companies. Many of each type are investing their own funds, in some cases in significant amounts.

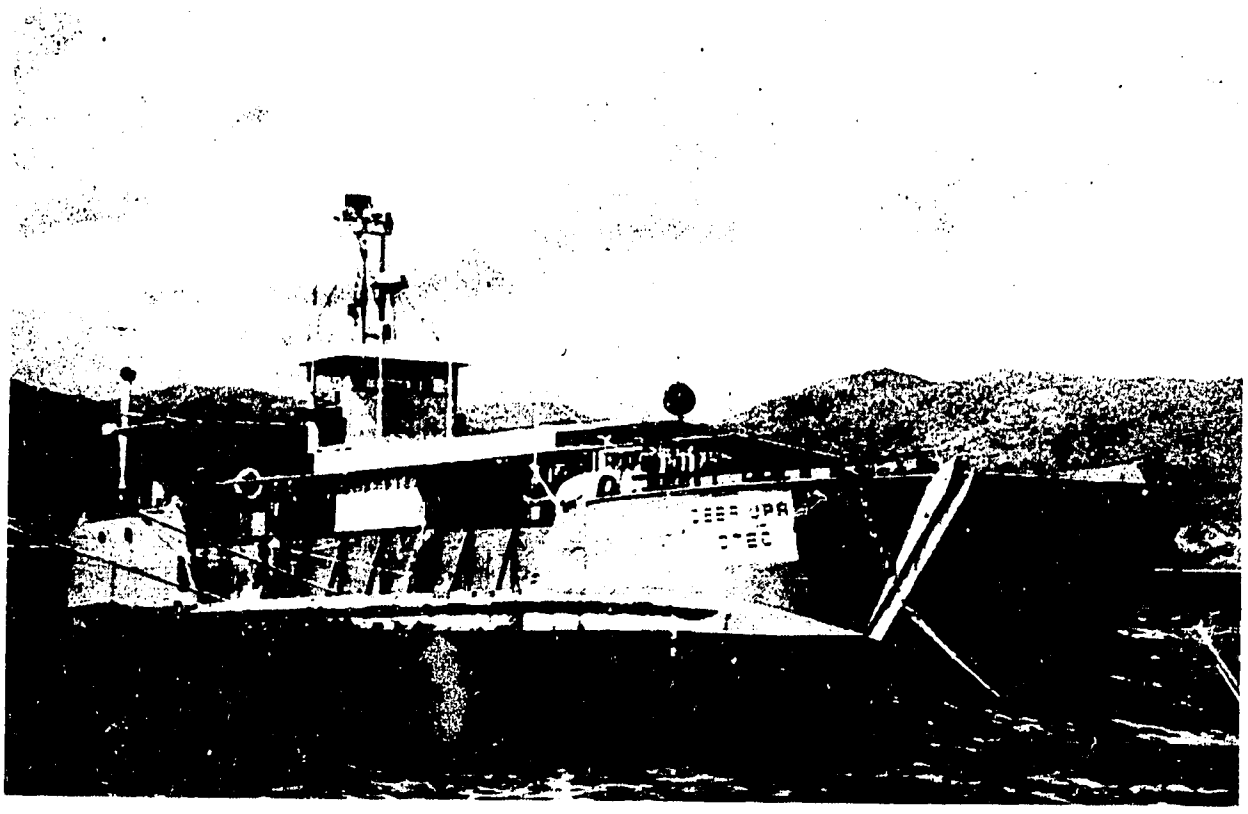
Private companies have been the leaders in ocean wave and ocean current research. Several large companies, as well as individual inventors, have made significant investments before seeking government funds to continue their projects. In addition to research, the private sector established an OTEC Utility Users Council and the Ocean Energy Council in 1979.

This one-megawatt heat exchanger will be tested on OTEC-1.

Private Activities

Completely funded by non-Federal sources, the 50-kilowatt "Mini-OTEC" was successfully demonstrated off the coast of Hawaii in 1979. With its total cost of $3 million contributed by industry and the State of Hawaii, this facility generated as much energy as previously predicted, assuaged fears about possible operating and environmental problems, and aroused considerable private sector interest in OTEC.

More than 200 companies are conducting government-funded OTEC research. Some are large corporations long involved in the



An apparatus for measuring changes in heat transfer and in microfouling has been installed on this Department of Energy-owned landing craft by the Center for Energy and Environmental Research of the University of Puerto Rico. The Center also is studying the biology of fouling and the corrosion of metals being considered for use in OTEC heat exchangers. The craft is moored off Punta Tuna, Puerto Rico.

Government Activities

The Federal ocean energy program was funded in past years at about $40 million annually. About 95 percent of this funding is being used for OTEC development. An engineering test facility, OTEC-1, was deployed in 1981 about 30 kilometers off the Kona Coast of Hawaii on a converted tanker to test components in an ocean environment. The facility can test components at sizes up to 1 megawatt.

Because Hawaii, Puerto Rico, the Virgin Islands, and Guam offer the best U.S. prospects for early commercialization, the Department of Energy pursued an "island" strategy for early demonstrations. The strategy could result in commercial OTEC plants of 40-200 megawatts being constructed for the islands by 1990.

The U.S. Congress passed legislation in 1980 establishing national demonstration, commercial targets, simpler licensing procedures, and maritime loan guarantees.

Projections

As expressed in recent legislation, the U.S.

commitment to obtaining energy from OTEC amounts to 10,000 megawatts (or 0.7 exajoules per year) by the year 2000.

Ocean Energy Systems in Brief

Present State of Development: Technology Ready. The basic technology for OTEC power has already been demonstrated at sea (Mini-OTEC and OTEC-1). A pilot-plant operation is needed to demonstrate the technology to potential utility and industrial investors. Many of the most crucial components in the development of economical systems are being tested, including warm- and cold-water heat exchangers, the cold-water pipe deployment, and corrosion and biofouling of heat exchanger surfaces exposed to seawater.

Resource Availability: Good. Extensive deployment of OTEC systems will require significant expansion of titanium-production capacity. However, use of alternative materials can overcome this potential problem.

Fossil Fuel Displacement Potential: Small. The contribution to the displacement of fossil fuels by the year 2000 is expected to be small in comparison to other renewable energy sources. However, OTEC can alleviate the oil dependence of U.S. tropical islands, Hawaii and Puerto Rico, by the early 1990s and provide some power to southeastern U.S. utilities by 2000. Tropical and coastal countries have large OTEC resources that can be used to supply substantial domestic electricity needs.

Cost-Competitiveness with Fossil Fuel: Fair. OTEC will become attractive in limited applications, such as those for generation of electricity in oil-dependent tropical islands. However, for large-scale use to provide power to the U.S. mainland, OTEC will not be competitive by 1990.

Degree of Social Acceptability: Good. Offshore operation of OTEC should not pose any large problems for urban populations. OTEC industry will provide employment opportunities, particularly in shipbuilding.

OTEC could also provide some secondary benefits such as enhanced fishing.

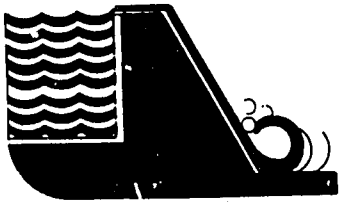
Environmental Acceptability: Excellent. Although some issues have been raised about possible changes in ocean ecology and in weather patterns, there is little demonstrated cause for concern. Flora and fauna in near-to-shore ecosystems could be disrupted.

Institutional Barriers to U.S. Commercialization: Moderate. Legal issues exist which relate to ownership of ocean resources, insurance, hazards to shipping, power transmission, and operation of OTEC plants. Development of an industrial base will be required.

Availability of Financing in the United States: Little. Large capital investments and risks will require demonstration of the pilot plant and some form of government assistance for deployment of early units.

Availability of Information in the United States: Fair. Cost and performance data is available from early experiments and OTEC-1. However, data from the operation of a pilot plant are believed to be necessary before large-scale investments would be considered by private industry.

Chapter 8
Hydropower



Introduction

Hydropower, which generates either electrical or mechanical power, is one of the world's oldest and most common renewable energy technologies. Grist mills, which use the mechanical force of water to grind grain, date back thousands of years. Since the 19th century, hydropower has been used to generate electricity for industrial and residential use. The early stages of the industrial revolution in the United States were centered in New England because of the readily available hydropower for the emerging mills. Because it was inexpensive, hydropower continued to be popular even after the advent of steam engines. Then, about a century ago with the development of electrical power transmission, hydroelectric plants for the first time could be located at some distance from the loads they served. Now, the largest rivers in the United States are dammed, and hydropower plants at these dams send electricity to cities and industries hundreds of kilometers away.

A conventional hydroelectric plant—one in which all of the electric power is produced from natural streamflow as regulated by available reservoir storage—uses a dam to create a water storage reservoir and artificial waterways to harness the energy of falling water to produce electric power. The amount of power thus captured is proportional to the size of the flow and to the pressure at which it is delivered to the machine, which depends on the vertical distance from the reservoir surface to the turbine level. The dependability of the power is reduced by the natural variability of the streamflow (often very great), unless a reservoir behind the dam smoothes out these variations.

Most of the largest hydropower sites in the United States have now been developed, and many of the remaining sites are in environmentally protected areas and national parks. In view of this fact and because of the recent rise in the cost of energy, interest is growing in developing smaller sites, especially those where hydropower equipment can be added to existing dams.

Hydropower is one of the two renewable energy sources already contributing significantly to the national energy budget. (Biomass is the other.) Conventional hydropower capacity in the United States now stands at about 65 gigawatts—nearly 3×10^{11} kilowatt-hours* annually, more than 3 percent of total U.S. energy demand, and more than 12 percent of all electricity needs. About 90 percent of this capacity is in large plants (30 megawatts or larger).

Present capacity represents a five-fold increase in 40 years. The greatest growth has occurred in federally owned plants,

*Units of 10^{11} kilowatt-hours are used, since approximately 10^{11} kilowatt-hours can be generated from one equivalent fossil fuel exajoule.

which now produce half of U.S. hydroelectricity. Investor-owned utilities control one-fourth, and the rest of the capacity is that of rural electric cooperatives, municipal utilities, and industrial concerns.

Technologically and commercially mature, hydropower possesses a secure industrial and financial base for expansion. It has an assured share in future energy production, though the present capacity can be expanded only to a limited degree. The limits of its role as a future energy source will probably be determined by the success with which a balance is struck among many competing demands for water resources, such as for irrigation or flood control.

Applications and Status

Nearly all hydropower in the United States is fed to electric utility networks, where it is blended with power from other fossil- or nuclear-fueled generation facilities to serve the entire spectrum of electrical energy uses. Because hydropower output can be adjusted quickly and easily to meet changing demands, electric companies commonly use it to supply the extra power needed during demand peaks. Where hydropower is plentiful and when streamflow is high, it is also used to supply baseload electricity for longer periods.

The Public Utility Regulatory Policies Act recently passed in the United States encourages the interconnection of small-scale hydropower plants and utility networks. This new law requires utilities to buy hydroelectricity at the utility's avoided cost—the cost the utility would otherwise incur by generating this additional energy itself. This Act became effective in 1981, and it is too early to predict its effect on future hydropower applications.

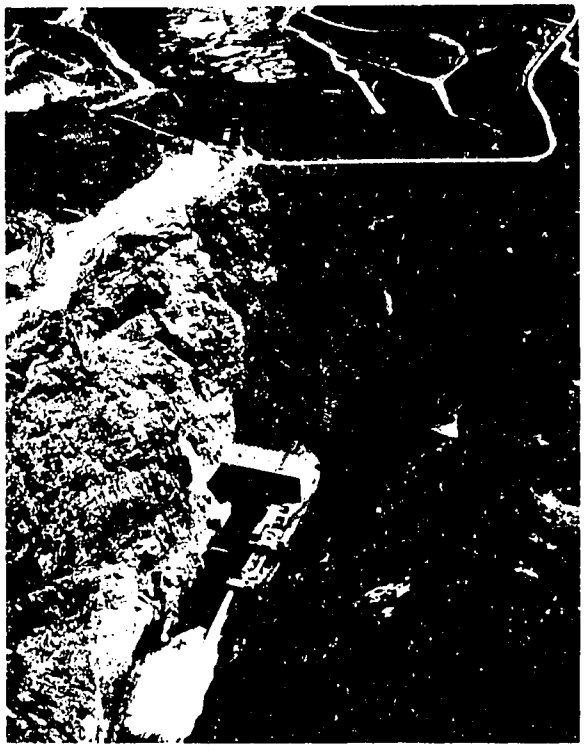
Hydropower bears a special relationship to some power-intensive industries. In particular, major hydropower facilities have a long-standing place in the electrolytic and electrothermal refining of metals. In the future, more hydropower sites distant from centers of concentrated electricity demand may be paired with plants that manufacture energy-intensive products such as fertilizers and aluminum.

Economics

The costs of developing hydropower sites vary widely, depending upon distance from centers of demand and other economic factors. The largest cost is that of the dam, which typically accounts for about 80 percent of total development costs. For instance, this varies greatly with the site and is related to the economics of other uses of water resources. The same water resource can be used for irrigation, municipal and industrial water supply, transportation, flood control, waste disposal, fisheries, wildlife, recreation, and the support of the ecosystem dependent upon the streamflow. While this multiple use is economically advantageous for hydropower, it also involves major constraints on hydropower production. Multiple use also accounts, in part, for the Federal Government's involvement in so many hydropower developments, since the government has interests in water resource development and management other than energy.

Since the capital cost of a hydropower installation is the chief determinant of the cost of the energy harvested from it, and because the costs of operating and maintaining hydropower facilities are low, the cost of borrowing money is a major factor in the economics of hydropower. Consequently, measures that affect the cost of money—such as investment tax credits, loan guarantees, and Federal financing—play an important part in determining the feasibility of new hydropower developments.

One economic factor not yet resolved is



The Blue Mesa Dam, here viewed from the air during its construction, produces 60 peak megawatts and 30 average megawatts, and demonstrates that earth dams can be used for very large hydropower projects.

that of capital depreciation. Rivers are permanent but reservoirs are temporary—sediment ends the economic life of those reservoirs that cannot be cleaned. Since most of the nation's great reservoirs are still relatively new, the problem of their depreciation has not been resolved. Until this problem is dealt with, hydropower cannot truly be called an inexhaustible energy source.

The economics of small-scale hydropower are less certain than that of larger facilities. Emphasis in the United States has so far been on rebuilding abandoned hydropower sites and on adding hydropower generators and equipment at existing dams. Federal incentives are offered in the form of low-cost loans for feasibility studies, tax advantages for investors, and guarantees that utilities will purchase energy produced in small hydro facilities. Recent evaluations suggest that existing dams capable of supporting installations of one megawatt or more capacity will be economical. Projections of 8 gigawatts for small-scale hydropower will require investments—mostly of local capital—of perhaps $10 to $20 billion by 2000; if these investments are made, present hydro capacity will increase by about 15 percent.

Storage and Other Systems Issues

Energy storage is inherent in hydropower installations. By being able to control the flow of water past a dam or series of dams—both to generate electricity during that portion of the day when it is most needed and to equalize the river flow over an annual or multiyear cycle—hydraulic engineers can maximize the value of hydropower in an energy system. At present, the trend in hydropower facilities is toward adding more power flexibility without greatly increasing the annual energy output, because hydropower's value in reducing total system energy cost is widely recognized.

One efficient means of using hydropower's flexibility is "pumped storage." Because most fossil-fuel-fired electrical generating plants are more efficient when producing a steady output, hydropower systems are increasingly used to store excess electrical production by pumping water from a lower reservoir into a higher one when demand for the electricity is too low to otherwise keep power production steady. When demand surpasses the level of this steady output, the pumps become generators, returning about 70 percent of the original energy to the utility system. There are two major categories of pumped-storage projects: pure and combined. Pure developments produce power only from water that has previously been pumped to an upper reservoir, whereas combined developments utilize both pumped water and natural streamflow to produce power. Pumped-

storage generating capacity now represents about 12 percent of U.S. hydropower generating capacity.

The inherent flexibility and energy-storage capacity of hydropower systems make them especially valuable when coupled with other renewable energy systems: since the outputs of photovoltaic, solar thermal, and wind power systems fluctuate greatly, energy storage systems are expected to play a vital role in their development. At present, hydropower is the most widely available and cheapest source of the power for backing up other renewable energy systems and maintaining the reliability of the utility system.

Barriers and Impacts

Barriers to expanding hydropower development include limits on the number of economical sites available, competition for finite water resources, and environmental impacts.

A major result of competition for water resources is the system of regulations, permits, and proprietary rights that now surrounds water use. Electricity can come from other sources, but only water can be used for irrigation, municipal and industrial needs, and maintenance of stream ecology. This fact and the value accorded to the environmental and recreational use of free-flowing rivers and streams has restrained the growth of hydropower in the United States.

The most serious environmental effects associated with hydropower use are those on aquatic organisms as a result of changes in the water's flow chemistry, temperature, and oxygen content. Clearly, the cost of mitigating these effects—for example, constructing a fish ladder around a dam site—is a potential limitation to hydropower development.

The risk that a dam may fail must also be considered, however unlikely or difficult to assess. Past failures have led to higher engineering standards aimed at reducing risks, though complying with these standards raises the cost of hydropower.

The social impacts of large-scale hydropower development resemble those of any big construction project. In particular, rapid but temporary local population changes occur and in turn give rise to related changes in demands for social services.

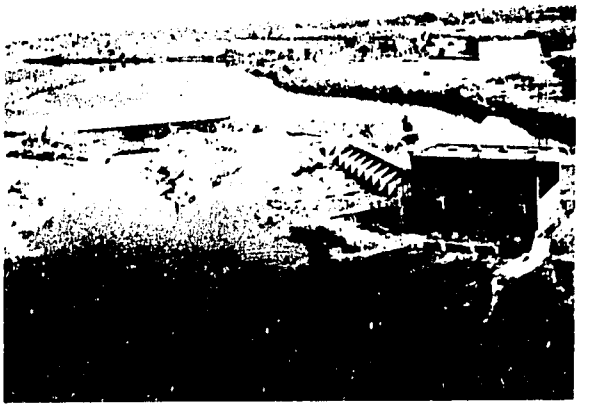
A unique concern associated with hydropower development is the extent of its impact on land use. Land valued for its agricultural, historic, or religious significance must sometimes be submerged behind a dam.

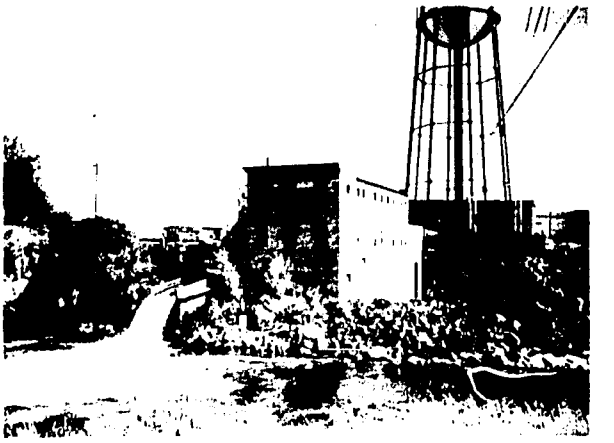
Private Activities

About half of all hydroelectric capacity (including that under construction) is non-federally owned. Projects scheduled for completion by 1990 will add to the non-Federal sector another 12 gigawatts of capacity, of which nearly half will be owned by investor-owned utilities. Hydropower generation in these new non-Federal facilities will be about 0.34×10^{11} kilowatt-hours per year of which about 40 percent will be by investor-owned utilities.

Within the private sector, additions to capacity rather than to generation indicate that hydropower will be increasingly devoted to peak loads that command higher energy prices. Accordingly, within the non-Federal sector, the average percentage of capacity utilized is expected to drop from the present 54 percent.

By the end of the century, the non-Federal capacity is expected to exceed 50 gigawatts, with annual generation of more than 2×10^{11} kilowatt-hours. Because of the long time lag involved in hydropower





These two low-head hydropower systems in Idaho Falls, Idaho, were reactivated as part of the Federal Hydropower Demonstration Program. The new generator in the unit at left is an eight-megawatt bulb unit that replaced an earlier, inoperative six-megawatt generator. The low-head and existing dam are typical of those in this program.

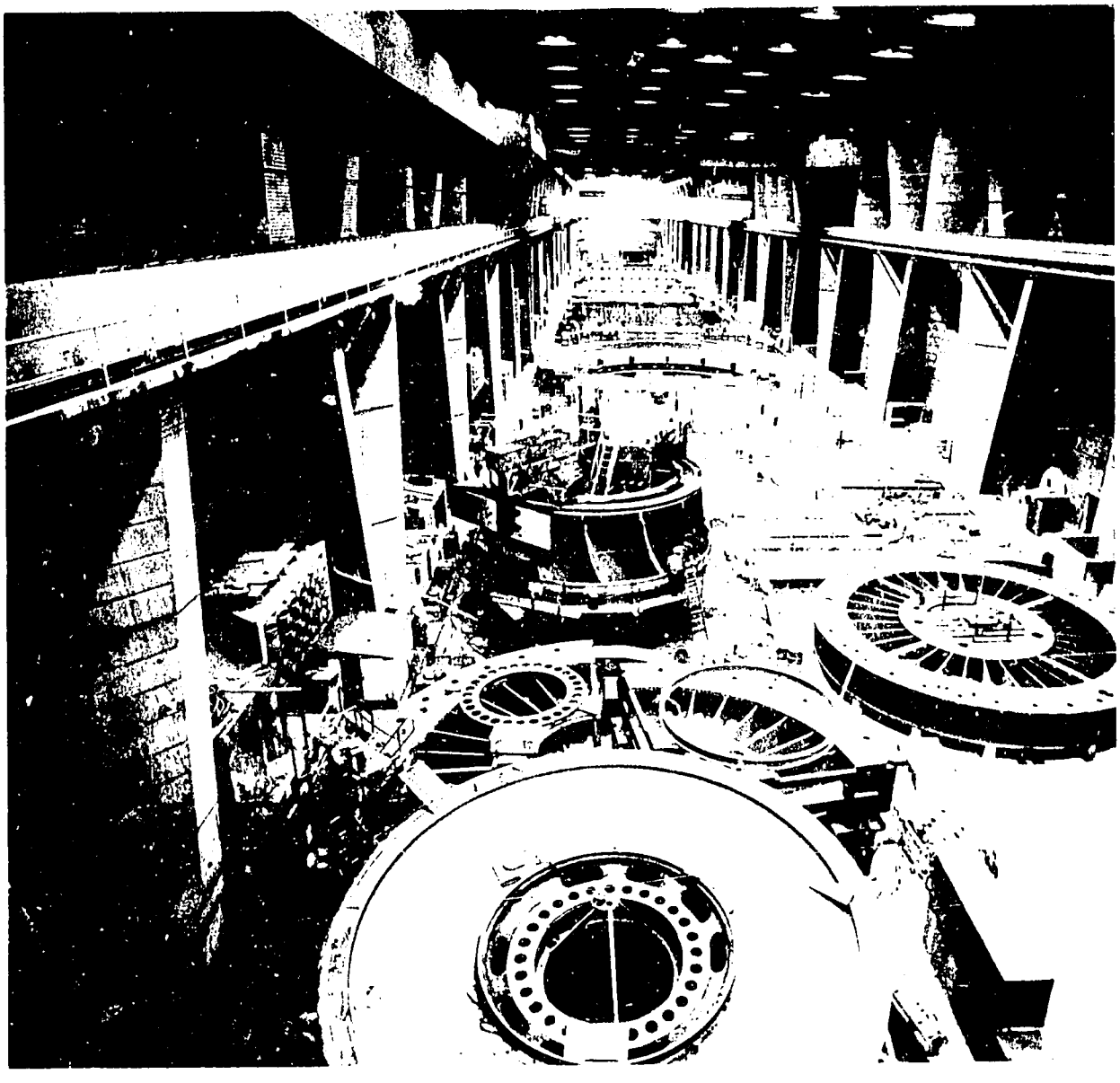
development, and because hydropower will always be used even if other sources are cut back, these estimates are considered relatively firm.

In the development of small-scale hydropower, private-sector activity is still relatively small. Most demonstrations have been requested by state, municipal, and cooperative organizations, which are given preference in financing. However, the Federal Energy Regulatory Commission (FERC) has received about 500 new license applications for small-scale hydro facilities out of an estimated 5,000 dam sites that are potentially suitable for development. The growth rate in receiving these applications has been very rapid; half were received in the last three months' reporting period of 1980. Of the preliminary permit applications (totalling 7.3 gigawatts), more than 40 percent were less than 30 megawatts and less than 30 percent were larger than 100 megawatts. The trend toward smaller size units in the United States is clear, since existing small hydro facilities comprise only about 10 percent of the total installed capacity. Many investors have committed capital, and several equipment manufacturers have developed equipment especially designed for small-scale hydropower applications.

In 1952 a resident of Idaho constructed a small hydro system on his property for $3000. It now produces $100-$150 worth of electricity each month—electricity that he uses to heat his home and to power the six furnaces, a hammermill, a large-ball mixer, and a crusher that he uses in his pottery business.

Government Activities

The Federal Government controls about 32 gigawatts of hydropower capacity. It has created organizations that design, construct, and operate hydroelectric facilities and market the energy. In general, the Army Corps of Engineers is the chief builder and operator of Federal hydropower installations. In the western United States, the Water and Power Resources Service of the Department of the Interior is responsible for constructing multiple-use water resource developments, primarily to support irrigation and only secondarily to generate hydropower. The Tennessee Valley Authority (TVA) and Water and Power Resources Service have the authority to construct and operate their own power facilities and to market the power. Five regional administrations of the



The interior of the third power plant at Grand Coulee Dam illustrates the complexity and scale of large hydropower facilities during installation.

Department of Energy sell federally generated hydropower to utilities and industries.

Through FERC, the Federal Government regulates and licenses the construction and operation of most hydropower installations. FERC exempts small-scale plants (under 5-megawatt capacity) from certain regulations and simplifies licensing procedures for them.

In various ways, all these agencies are working to expand large-scale hydropower capacity. New construction projects have been approved and construction funding appropriated by the Congress for about 7.5 gigawatts of additional capacity, and feasibility and design studies are under way on an additional 7.5 gigawatts of capacity. A further increase in capacity is expected as improvements are made in existing facilities to upgrade their capacity.

Projections

The United States will probably have

around 100 gigawatts in hydropower capacity by the year 2000. This represents growth of approximately 50 percent, or about 2 percent per year, for the next twenty years. For large-scale hydropower, the projection is not likely to change greatly, partly because so much time elapses between carrying out initial feasibility studies of a major site and completing the project. The total hydropower capacity available for development after the year 2000 appears to be less than 100 gigawatts.

With respect to small-scale hydropower, the present Federal program objective is to assess the potential of this resource as a contribution to U.S. generating capacity. Substantial disagreement remains as to what that capacity may be. The projection suggested by the Domestic Policy Review of Solar Energy, 8 gigawatts, is intermediate between low and high estimates ranging up to 20 gigawatts. (Existing small-scale hydropower permit applications total more than 3 gigawatts.) However, until the uncertainties about the effectiveness of developmental incentives are resolved and environmental and other barriers are surmounted through research and experience, it is impossible to establish a definite projection for small-scale hydropower development.

Hydropower in Brief

Present State of Development: Commercially Ready. Hydropower is a mature technology. Federal encouragement of small-scale hydro projects is facilitating development of new components and systems.

Resource Availability: Very Good. Most construction materials are locally available. Procurement of power plant equipment requires lead times of one year or longer.

Fossil Fuel Displacement Potential: Good. Future expansion of existing U.S. hydropower is limited. However, significant additional displacement of fossil fuels could result from use of small-scale hydroelectric plants.

Cost-Competitiveness with Fossil Fuel: Excellent. Hydropower is extremely cost-effective in view of increasing fuel costs. Development of marginal sites is becoming economical.

Degree of Social Acceptability: Good. Institutional and legal means for dealing with social issues are adequate, and precedents are well established.

Environmental Acceptability: Very Good. New major dam projects can disrupt plant and animal life, and risk of dam failure may be a major environmental concern.

Institutional Barriers to U.S. Commercialization: Few. Hydropower is closely regulated. Licensing procedures, which are complex and time-consuming, are being relaxed for construction of small-scale systems at existing dams.

Availability of Financing in the United States: Very Good. Financing sources are well established for both private and public hydropower projects. Special investment tax credits are available for small-scale hydropower.

Availability of Information in the United States: Excellent. Design, construction procedures and cost are well documented and readily available. Data for small-scale hydropower are available in handbook form.

Chapter 9
Geothermal

Introduction

Geothermal energy resources are concentrations of the internal thermal energy stored in the earth's subsurface rocks and fluids at accessible depths. Geothermal energy can be used for electric power production, residential and commercial space-heating and cooling, industrial process heat, and agricultural applications. In the order of technological readiness, the three principal types of geothermal systems are hydrothermal, geopressured, and hot-dry rock.

Hydrothermal systems include hot water and steam trapped in fractured or porous rock relatively near the surface. Electricity is being produced now at The Geysers geothermal field in California, and power production is expected to become economical soon in several other western states. Hydrothermal heat is being used for non-electric applications in numerous western states, and it could now be used at many more sites, including some in the East. (Recoverable U.S. hydrothermal resources at temperatures above 150°C are estimated to total 90-140 exajoules. Resources at temperatures between 90° and 150°C are believed to amount to 200-300 exajoules.)

Geopressured systems are hot-water aquifers containing dissolved methane that is trapped under high pressure in deep sedimentary formations, primarily along the Gulf Coast of the United States. Commercial production of energy (primarily methane) from these large resources may begin in the late 1980s. (Recoverable thermal energy from geopressured fluids are believed to total 30-300 exajoules, while geopressurized methane resources amount to 75 to 800 exajoules.)

Hot-dry rock systems are accessible geologic formations that are abnormally hot but contain little or no water. Usable energy is extracted from these formations by circulating a heat-transfer fluid, such as water, through deep wells that are connected by manmade fractures in the rocks. Commercial production of energy from these very large resources is expected to begin in the early 1990s. (Recoverable hot-dry rock resources in the United States are believed to total 200-2000 exajoules.)

The greatest potential for hydrothermal development, particularly for electric power generation and direct heat applications that require relatively high temperatures, lies in the western United States. On the Atlantic Coast and in the Southeast, prospective sites for hydrothermal development are associated with low-to-moderate-temperature reservoirs. Known geopressured resources are located primarily along the Texas and Louisiana Gulf Coast, but there is evidence of geopressured systems in deep sedimentary basins elsewhere in the United States. Hot-dry rock resources are widespread in the western states and may exist also in the eastern states.

At present, the worldwide installed geothermal electric capacity is about 2500 megawatts, including about 30 percent of it

Progress at the geothermal facilities in Puna, Hawaii, has been so successful that 20 megawatts of capacity may be available before 1985.

in the United States. About this same amount of geothermal electric capacity is expected to be added by 14 countries by 1985. About 10 countries also make significant direct use of geothermal energy, including about 8,300 megawatts (thermal) for space conditioning, water heating, agricultural, and industrial applications.

Applications and Status

Since geothermal water and steam cannot be transported for long distances economically, they must be used or converted to more portable forms of energy at their production site. Electric power can be produced reliably at competitive costs from hydrothermal resources hotter than about 150°C. This process is of great interest to electric utility companies and specialized geothermal companies that acquire leases, explore for, and develop the geothermal resources with the intention of producing electric power for sale to utilities. Already, 912 megawatts of electricity is being commercially produced now at The Geysers geothermal steam field in California, and electric power development using hot water reservoirs has begun at two sites in California's Imperial Valley. U.S. utility companies have announced their intentions to build hydrothermal electric generating

plants to produce additional generating capacity totalling more than 1000 megawatts. Several municipalities have begun to develop geothermal energy for public use, and some large industrial users who own or lease land containing geothermal resources are evaluating those resources in view of their own needs for electricity.

About 115 thermal megawatts of hydrothermal direct heat is being used in a dozen western states for space heating and for industrial and agricultural processes. The principal direct geothermal heat users are energy-intensive industrial firms, municipalities, school districts, and hospitals (which use geothermal energy for space heating). These lower-temperature applications are widely distributed across the country.

In agriculture and aquaculture, the direct use of hydrothermal energy applications is increasing. Geothermal energy is being used to heat process water in an ethanol plant in Colorado; a similar use is planned for a geothermal industrial park in eastern Oregon. In South Dakota, the Diamond Ring Ranch extracts energy from a low-temperature geothermal resource to heat farm buildings, to dry grain, and to warm drinking water for the ranch's livestock. Geothermal fish hatcheries are operating in California, Colorado, Idaho, Oregon, Utah, and Wyoming. The use of warm, clean geothermal water year-round enhances the growth rate and improves the taste of the fish. Fish Breeders of Idaho have grown catfish in geothermal water for more than six years—of particular interest because Idaho's climate is too cold and the growing season too short to operate a fish farm without benefit of heated water.

Geopressured energy use is best viewed as a mid-term energy option. Tests of prototype production wells in Louisiana are to be made through 1985. If they show that the technologies are feasible, commercial development of geopressured resources could begin in 1987. In contrast, extensive use of hot-dry rock resources through water injection is a long-term prospect, although tests are already under way. A 5-megawatt thermal loop has been in operation in New Mexico, and energy-extraction experiments there and at a second site should be completed by 1987. Geopressured technology demonstration activities could begin in 1988, followed by commercial deployment of hot-dry rock technology around 1990.

Economics

Power generation from high-quality hydrothermal steam has long been economical. Recent increases in the prices of other fuels, coupled with advances in geothermal technology, have also improved the comparative cost of electric power from high-temperature, liquid-dominated hydrothermal resources. Electric power from a number of geothermal areas is now competitive with fossil-fueled or nuclear power. However, many geothermal sites are in regions with no significant demand for energy.

The development of geothermal resources generally involves a large initial investment in exploration and wellhead equipment. The costs of new designs must also be borne since each installation is unique and the generating equipment must be adapted to temperatures and pressures much lower than those for which conventional fossil-fueled steam plants are designed. On the other hand, even though the energy conversion efficiency from geothermal waters is low, so are the operating costs associated with them. Current geothermal production costs range between 1.5¢ and 6¢ per kilowatt-hour, with the costs split about equally between field development and construction, and operation of the generating plant.

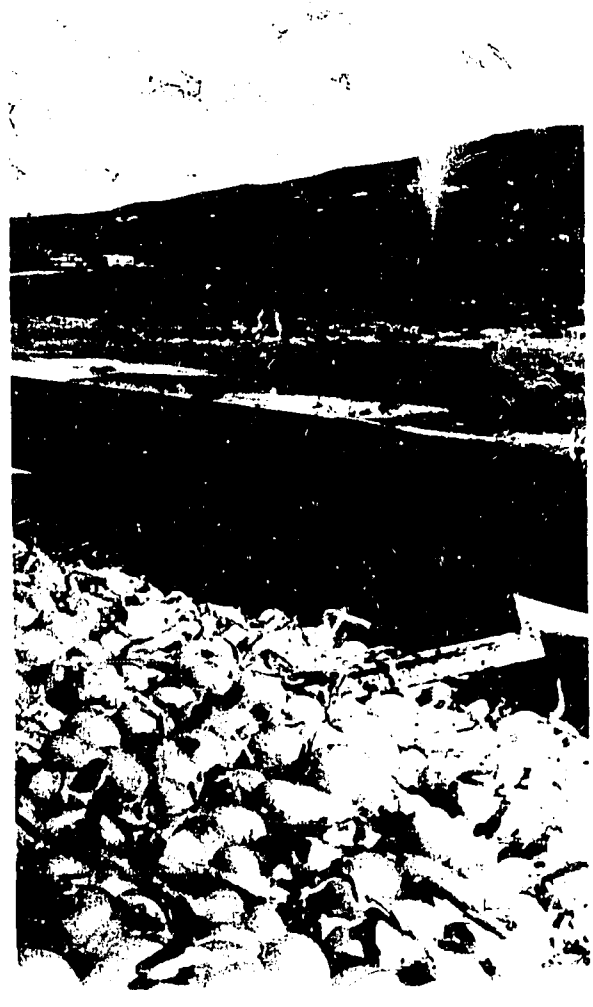
The commercial development of hydrothermal electric power is also inhibited by uncertainty about how long the reservoirs will last and by lack of economically proven technologies for all but the higher-temperature resources.

Numerous feasibility studies and demonstration projects have shown that low- and moderate-temperature hydrothermal reservoirs also can be reliable sources of low-grade heat at attractive costs. Costs from 50¢ to $2.50 per gigajoule have been reported.

The Oregon Institute of Technology has examined the feasibility of using the thermal waters of Sol Duc Hot Springs in Olympia National Park for heating Park Service facilities. Preliminary calculations indicate that a geothermal space-heating system costing $40,000 would save about $300,000 in fuel costs over twenty years. If the Park Service installs this system, it will be the first time geothermal energy has been used for space heating at a major national park.

The economic feasibility of recovering energy from geopressured resources will depend on the amount of methane a well can produce. This is a highly uncertain factor at present. The commercial development of hot-dry rock is also possible in the long term, but technologies for drilling and fracturing as well as water injection and recovery must be improved significantly if obtaining energy from this potentially large resource is to become economical.

To offset the risks in developing geothermal energy, the U.S. Congress has instituted a number of economic incentives for developers. These include loan guarantees and special tax incentives similar to those extended to developers of other energy resources in the United States.



At Brady Hot Springs, Nevada, a vegetable-dehydration plant uses geothermal energy as the sole source of heat for both washing and drying 10,000 pounds of raw onions per hour. The plant uses 110°C geothermal water drawn up from several hundred feet below the ground to displace 10 million cubic feet of natural gas per month. The project received a federally guaranteed loan and partial funding from the Department of Energy.

Barriers and Impacts

The use of geothermal resources involves environmental constraints, even though the exploration and development require neither massive facilities nor extensive land disruption.

Geothermal fluids often contain toxic or offensive concentrations of hydrogen sulfide and other undesirable gases. The odor of hydrogen sulfide is offensive even when it is not unhealthy; at higher concentrations hydrogen sulfide is toxic, corrosive, and a health threat. Ammonia, radon, and other gases may also be released and could cause a problem. Salt and other contaminants in geothermal fluids may clog the pipes and other equipment.

Another impediment to geothermal development is land subsidence or other degradation. Withdrawing fluids from some underground geothermal reservoirs may cause the land above them to drop. Furthermore, extracting or injecting geothermal fluid may set off small earthquakes. Disposing of hydrothermal and geopressured fluids, which may be highly saline and toxic, requires cleanup before surface release. It also requires making sure that surface waters and ground waters are protected from accidental surface spills and leaks from brine-disposal wells. Any solid wastes generated in the operation of a geothermal plant must also be carefully controlled. These can arise from the drilling operation, from pollution control sludge (generated during hydrogen sulfide removal), and from the removal of particulate matter from the reservoir fluids.

A positive social impact of the development of geopressured resources—a development boom—could affect the central regions of Louisiana and Texas. These areas underwent decades of economic expansion as large natural gas and oil deposits were discovered and developed, but income to the states from royalty payments on production from those deposits declined in the 1970s. Geopressured gas revenues could compensate for dwindling royalties from conventional sources.

The social impacts of developing hot-dry rock resources remains highly speculative since commercial development is not expected until the 1990s.

Private Activities

Private organizations have so far played a major role in developing geothermal energy. The largest geothermal project in the world, the electric power complex at The Geysers, in California, was initiated and developed privately. However, similiar high-temperature, dry-steam hydrothermal resources are rare in the United States. The more abundant liquid-dominated hydrothermal resources involve higher risks and costs, which inhibit their rapid private development.

A 10-megawatt electric plant in Southern California, which was tested at the start of 1980, is the first U.S. plant to generate electric power from a liquid-dominated resource, and the first geothermal plant of substantial size in the world to utilize a two-working fluid process. Two other 10-megawatt electric plants will be completed in California before the end of 1981.

Most geothermal engineering companies are small, special-purpose engineering concerns that pioneer plant-design concepts or plant components. But some large architectural and engineering firms also are involved in designing and building major geothermal plants. These engineering companies see themselves as technical bridges between the developer and the final user of the geothermal energy resource. Although most prefer to limit their role to design and construction, some have marketed geothermal energy to users (most frequently utilities) and a few have underwritten project risks.

Recently, small- and medium-sized firms specializing in geothermal exploration, engineering, and support services have entered the field. Manufacturers of energy-conversion equipment now sell turbines, heat exchangers, and other hardware designed for geothermal service. Most of the major energy companies are becoming involved in the development of geothermal energy in one form or another. The main

objective of these energy companies is still the production of steam for electric power. They have shown little interest in direct heat applications, primarily because most such projects are small.

The Hawaiian Geothermal Development Group has completed preliminary design of a three-megawatt electric well-head generator which should produce economically competitive electricity from a 185° C hydrothermal reservoir in Puna, Hawaii.

Government Activities

Department of Energy support for geothermal energy development has been approximately $155-$160 million per year for the last three years. Another $16-$19 million each year has been spread among the seven other member agencies of the Interagency Geothermal Coordinating Council—chiefly the Departments of Interior, Defense, and Agriculture, and the Environmental Protection Agency.

The overall objective of the geothermal program is to transform the many types of geothermal resources into an array of technically, economically, and environmentally sound commercial ventures. The program aims both to remove barriers to the immediate industrial development of resources that are now potentially economical and to ensure the mid-term and long-term development of resources whose uses are technically and economically less certain. The program features R&D projects directed at reducing the costs of technologies as well as providing financial incentives (including the Geothermal Loan Guaranties Program) aimed at sharing the private developers' front-end risks in exploiting new geothermal reservoirs.

The Department of Energy's program can best be described in terms of the five modes of using geothermal energy to advantage. It encourages the use of high-temperature hydrothermal resources for electric power generation. Technologies for exploiting hydrothermal resources for electricity are available and cost-competitive, and they are being used today on a limited scale. The Federal program's emphasis is on accelerating industry's exploitation of the resource base. To this end, the government provides tax incentives and loan guaranties, it sponsors applied R&D to resolve critical technical problems, and it assists in the confirmation of new reservoirs. The Federal program also includes support for

full-scale demonstration projects. For instance, a 3-megawatt electric wellhead generator system is scheduled to begin operating in 1981 near Puna, Hawaii, and a commercial-scale 50-megawatt electric flash-steam demonstration plant is expected to be operational in 1982.

Other Federal programs focus on using moderate-temperature hydrothermal resources for electric power production. A much more widely available resource than high-temperature hydrothermal, moderate-temperature hydrothermal systems require the development and demonstration of binary-cycle electric power generating systems (those based on the use of a turbine generator driven by an organic working fluid). The government's program for developing this resource is designed to bring the technology to maturity and economic competitiveness by about 1985. Specifically, it entails R&D directed at reduction of development costs, confirmation of reservoirs, and plant demonstrations. (A 5-megawatt electric binary-cycle power plant in Idaho will begin operation in 1981, and a 50-megawatt electric binary-cycle demonstration plant is scheduled to be constructed in California.)

Government programs also supported the use of hydrothermal resources (at all temperatures) for direct heat applications. Technologies for using geothermal energy directly for space heating and for process heat are well developed and economical, though more work is needed to identify reservoirs close to areas where they can be used. To stimulate independent industrial activity, which is just beginning, the Federal geothermal program supported direct-use demonstration projects, reservoir confirmation activities, financial incentives and risk sharing, technology transfer (through regional technical assistance centers), the reduction of legal impediments to development, and R&D to reduce costs and increase reliability. Twenty-two cost-shared direct-heat demonstration projects are now under way, most of them for space conditioning and district-heating applications.

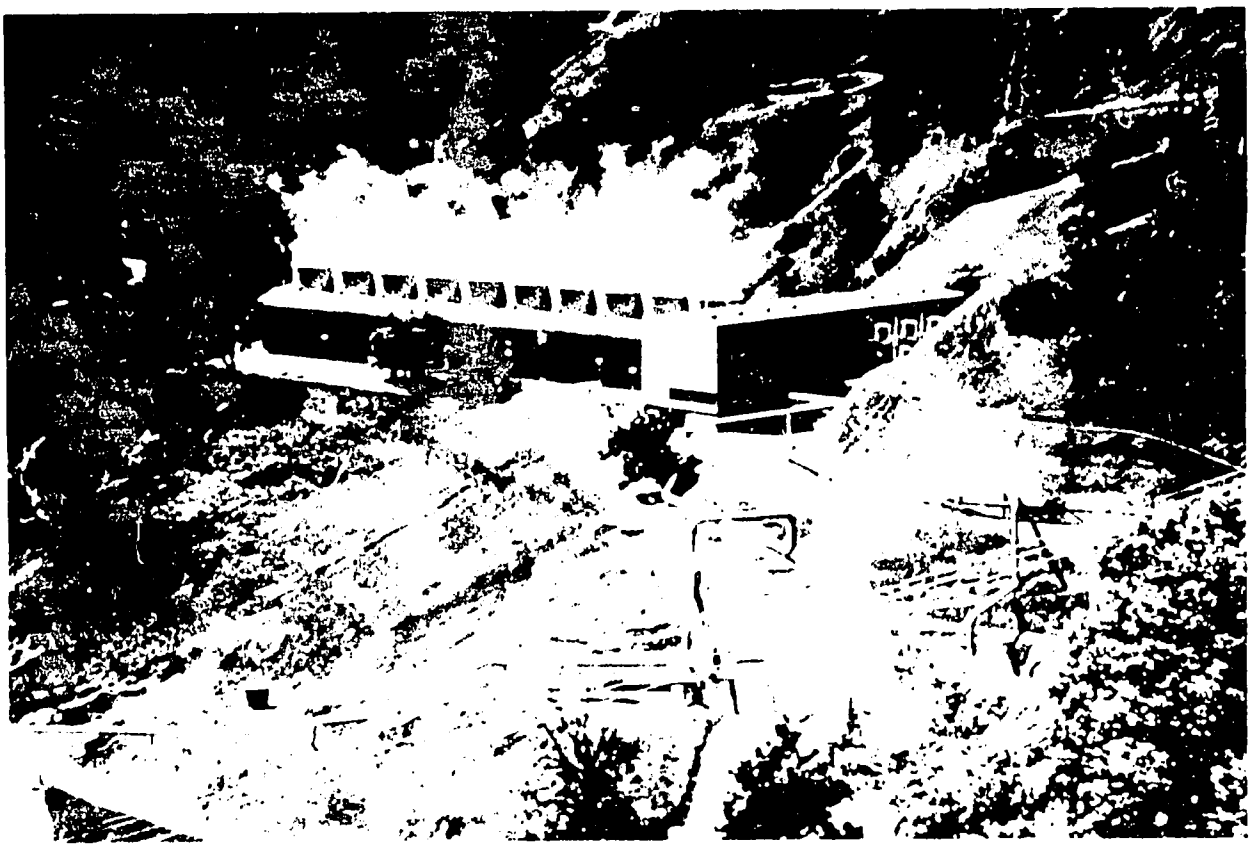
The Federal program provides for use of geopressured resources—primarily methane, but also thermal energy for electric power production and direct heat applications. The Gulf Coast oil and gas industry is expected to develop this resource if production is demonstrably economical. Current program activities center on assessing the technical performance and economics of these resources through extensive tests of both existing wells and new, specially designed wells.

The final mode of geothermal energy covered in the Federal program is the hot-dry rock resource. The technology for exploiting the enormous heat content of dry geothermal resources is under development and has been proven technically feasible on a pilot scale at one site. Some of the current program emphases are on research and development aimed at improving the energy-extraction technology, on reservoir engineering, and on the economics of exploiting hot-dry rock resources. Another emphasis of the program is to develop a second test site, one whose geological characteristics differ from the first.

Projections

Surveys of the geothermal industry's intentions indicate that about 2 gigawatts of geothermal electric power capacity will have been installed in the United States by late 1985. Some 65 percent of this would be at The Geysers, while the remainder will be at liquid-dominated hydrothermal reservoirs in the western United States.

The Interagency Geothermal Coordinating Council geothermal market projections for 1985 forecast a total of 0.4 exajoules per



The Geysers Power Plant in Hawaii, with a capacity of 912 megawatts, is the world's largest geothermal facility. This capacity should double by the year 1985.

year, which would be about 0.5 percent of total U.S. energy production. Of this total, about two-thirds is expected to be in electric power production with most of the rest in direct heat applications.

Geopressured resources in the United States are known to contain enormous amounts of energy. If the results of current research are favorable and the environmental impacts can be minimized, rapid commercial exploitation of these resources should occur, beginning in the mid-1980s. While the forecast for methane production by 1985 is low, by the year 2000 about half of all geothermal energy is projected to come from geopressured methane—a total of perhaps 3 exajoules per year, or more than 3 percent of the annual U.S. energy production. By the year 2000 about 2 exajoules per year is projected to be in electrical applications from hydrothermal sources and about 1 exajoule per year in direct thermal applications. In short, contributions from these two energy sources are projected to grow by factors of eight to ten between 1985 and 2000.

Even greater quantities of energy are believed to be present as heat in hot-dry rock formations. As yet, however, the locations and characteristics of these formations are not well known and the techniques for extracting the heat are not fully developed. With available technical knowledge, it is not possible to determine whether the cost of recovering energy from hot-dry rock resources will be low enough to permit their exploitation by industry. If it is, commercial development may begin in the 1990s.

Geothermal Power in Brief

Present State of Development: Commercially Ready. Several hydrothermal power systems have been in operation for decades. Geopressured and hot-dry rock systems are under development with commercialization expected in the 1990s.

Resource Availability: Fair. Heating applications are limited and power generation equipment requires special corrosion-resistant materials which can withstand the effects of brine and other high mineral concentrations usually found in geothermal reservoirs.

Fossil Fuel Displacement Potential: Fair. Geothermal resources are not found worldwide. Hydrothermal reservoirs are depletable, and experience is lacking in determining the optimum rate of removing the energy.

Cost-Competitiveness with Fossil Fuel: Good. Where a geothermal resource is abundant and of high quality, the investment in construction and operating costs is competitive when compared to generation of electricity or direct heating by other methods.

Degree of Social Acceptability: Fair. Local acceptance is not assured because of possible subsidence, noise, brine and effluent disposal, and odor of hydrogen sulfide. Where these problems are not present, the acceptance should be good to excellent.

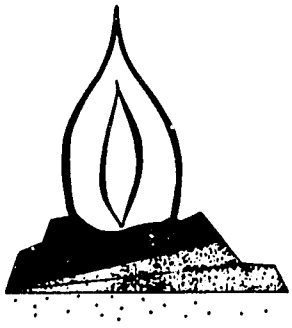
Environmental Acceptability: Good. Since the required extraction and power generation facilities are limited, with some exceptions, environmental impact can be controlled. Some environmental controls may be required to protect air quality, and ground and surface water.

Institutional Barriers to U.S. Commercialization: Moderate. Most geothermal developments will require a lengthy environmental review. Since the hydrothermal resource is depletable, there may be some utility rate structure problems.

Availability of Financing in the United States: Good. Because known geothermal resources are a dependable and uninterruptible source of energy during their lifetime, capital investment should be readily available. Also, geothermal resources can be developed in incremental stages.

Availability of Information in the United States: Very Good. The long history of geothermal development has made considerable information available. Resource and technology information is being widely distributed.

Chapter 10
Oil Shale



Introduction

Oil shale is a fine grained sedimentary rock containing a brown to dark gray organic material called kerogen. Kerogen, a complex molecular substance, is composed mainly of carbon and hydrogen, with some nitrogen, oxygen, and sulfur. Heating oil shale to about 480°C transforms the kerogen into a viscous liquid called shale oil, plus some gas and solid coke. Because shale oil does not appear in nature as a liquid combustible substance and is the product of treating a natural material, shale oil is termed a "synthetic" crude oil.

The United States has some 1.8 trillion barrels of oil in oil-bearing shales in three western states: Colorado, Wyoming, and Utah. About one-third of this oil from shale is believed recoverable from 43,000 square kilometers of these lands. The shales range in quality from about 40 to more than 300 liters of oil per metric ton of rock. (This is equivalent to about 0.3 to 1.8 barrels per metric ton of rock.) The richest layers of the deposits are more than 30 meters thick; together, lean and rich sequences of shales are over 500 meters thick in Colorado.

Comparing U.S. shale resources with world reserves of conventionally available oil helps put the scale of the resource into perspective. The 600 billion barrels recoverable from western oil shale compares to 350 billion barrels in the Middle East oil reserves, and is estimated to be about equal to the known world reserves of oil recoverable by conventional methods of drilling and pumping. These estimates change periodically, however. New discoveries, such as those in the North Sea, the USSR, China, and Mexico, have helped push the world oil reserve tally upward in the past several years.

Oil can be extracted from shale by either of two basic processes. In the first, the rock is mined and crushed. In the second, the rock is fragmented while still "in situ"—in the ground. In both processes, the rock is then heated (retorted) to vaporize the kerogen. Finally, the oil vapor is condensed to a liquid and collected for further processing. (A third process combines the mining and in situ approaches.)

Developing proven, economical, commercial processes for extracting oil from shale in the United States could have worldwide importance. Such processes could be modified and applied in many countries with shale deposits.

Applications and Status

Shale oil will compete in the petroleum market. After some initial treatment, or upgrading, crude shale oil can be used as refinery feedstock or boiler fuel. However, existing refineries may require some modification before they can process shale oil. Oil shale processed in pilot projects has been converted into a wide range of fuel distillates, including motor gasoline, jet airplane fuel, and diesel engine fuel.

Oil shale can also be a source of a gas suitable for pipeline transmission. Moreover, minerals found in some of the shales including nahcolite, alumina, and sulfur, are potentially important, since the recovery of by-products in oil shale operations could make shale oil recovery more economical.

Economics

Historically, the cost of producing oil from shale has been higher than the value of the oil. Depending on which extraction processes are used, oil from shale is now estimated to cost from $32 to $62 per barrel with a 12 to 15 percent return on investment. The capital investment required ranges from $1.7 billion to $2 billion for a facility able to produce 50,000 barrels per day. In addition, operating costs amount to tens of millions of dollars annually.

Barriers and Impacts

Significant barriers stand in the way of a commercial-scale oil shale industry. Because shale deposits are in remote locations, developers will have to build new towns, roads, airports, railroads, electric power plants, water-supply and transportation facilities, power lines, and communication systems at costs of hundreds of millions of dollars. Also, there is a scarcity of skilled craftsmen and technical workers needed to construct, operate, and maintain the oil shale plants. Firms with the necessary design capabilities have long backlogs of work for other technical projects, including facilities for producing other synthetic fuels, and for gasifying and liquefying coal.

Controlling the pollution of air and water is a major concern because of the immense volume of materials involved. Mining a million or more metric tons of shale each day, disposing of the waste after the oil is extracted, and stabilizing and reclaiming the area where the waste is deposited pose major technical, financial, environmental, and logistical challenges. Just one surface retorting plant with a 50,000 barrel-a-day capacity will require disposal, stabilization, and reclamation of almost 20 million metric tons of waste rock each year. Other serious problems are the disposal of relatively small amounts of waste water containing organic constituents, pollution caused by the materials handling equipment, and pollution caused by the sulfur compounds contained in the spent shale.

Availability of water supplies may be a constraint. At present, water can be found for production equaling only several hundred thousand barrels per day, so water-development projects will be needed. Each barrel of shale oil will require from two to seven barrels of water, depending on which process is used. In some processes, water may be recycled and used again; but even so, ensuring that adequate water supplies are available will be a problem in western regions, where competition for water is already intense.

Most discussions of the social impacts of oil shale development center upon the need for new communities to house thousands of workers, their families, and the other people attracted to the business opportunities associated with this type of development.

Private Activities

Nearly every major American oil company has a financial interest in shale oil. Some own shale lands and others are actively developing retorting and refining technologies. Some of these companies are entering into commercial ventures where the feasibility studies have been partially funded by the Federal Government.

A portion of the Rio Blanco Oil Shale Company's facilities in western Colorado.

The most ambitious private endeavors include the development of four 2,100-hectare prototype tracts in Colorado and Utah. One tract—the site of an in situ pilot operation since October of 1980—is being developed by Rio Blanco Oil Shale Project, a joint venture of Standard Oil of Indiana and Gulf Oil Company. Rio Blanco hopes to develop a large open-pit mine with surface retorts which will produce 78,000 barrels of shale oil daily by 1987. The second Colorado tract, being co-developed by Occidental Petroleum and Tenneco, provides a testing ground for the modified in situ technology. It has a 1986 production target of 57,000 barrels of shale oil per day. Other developers of Colorado shale include Exxon USA and Tosco (46,000 barrels per day), Union Oil of California (9,000 barrels per day), and Multi Mineral Corporation, which is extracting secondary shale oil and alumina in a nahcolite-mining operation.

Less ambitious, but potentially significant because of its low capital costs, is an in situ demonstration in Utah by Geokinetics Corporation. The Geokinetics horizontal process requires a capital investment of only about $18 million for an operation with a 2,000 barrel-per-day capacity.

While the total private expenditures for oil shale have not been tabulated, the amount is obviously in the tens of millions of dollars annually and rising rapidly. An example gives a sense of the financial scale involved. In 1974, nine companies put up almost $450 million for leases to pioneer commercial oil shale development on Federal land.

Government Activities

The U.S. Government has spent about $150 million in R&D on several technologies to help develop a commercial-scale oil shale facility that is technically and economically feasible. The government

plays a major role in oil shale development, partly because it owns 80 percent of the western oil shale lands. Moreover, private land cannot be developed without Federal cooperation because government permits are needed to build roads, pipelines, and transmission corridors across Federal land.

Several agencies—principally the Departments of Energy, Interior, and Defense—are taking part in these development activities. The Department of Energy is funding three experimental oil shale projects to develop in situ processing technologies. It allocated $28 million for oil shale research in 1980 and another $36 million in 1981. Most of its work is on in situ technologies, though $15 million has been devoted to a two-year project on surface retort design.

The Department of Interior has been active in oil-shale development for decades. Currently, it leases four 2100-hectare tracts, two each in Colorado and Utah, to private industry. Development has been under way on the two Colorado tracts since 1974, and the leases are expected to be renegotiated and extended to new tracts in 1981. In Utah, litigation has held up the development of the federally leased tracts.

The Department of Defense has also participated in oil shale programs; the Navy funded a project in Colorado that has produced about 100,000 barrels of shale oil. The oil has been refined and upgraded to produce five different fuels, including motor gasoline and various grades of diesel and aviation fuels. The Department of Defense has successfully tested these shale-based fuels extensively in ships and planes.

Future oil shale development will be supported by financial assistance provided through the U.S. Synthetic Fuels Corporation, a quasi-governmental corporation created by Congress in 1980.

Projections

Projections range between production of 250 to 500 thousand barrels of shale oil a day by 1987 and one to two million barrels a day by 1992.

Oil Shale in Brief

Present State of Development: Demonstration Stage. A few pilot plants exist. Engineering problems with respect to modifed in situ processes and above-ground retorting need to be resolved.

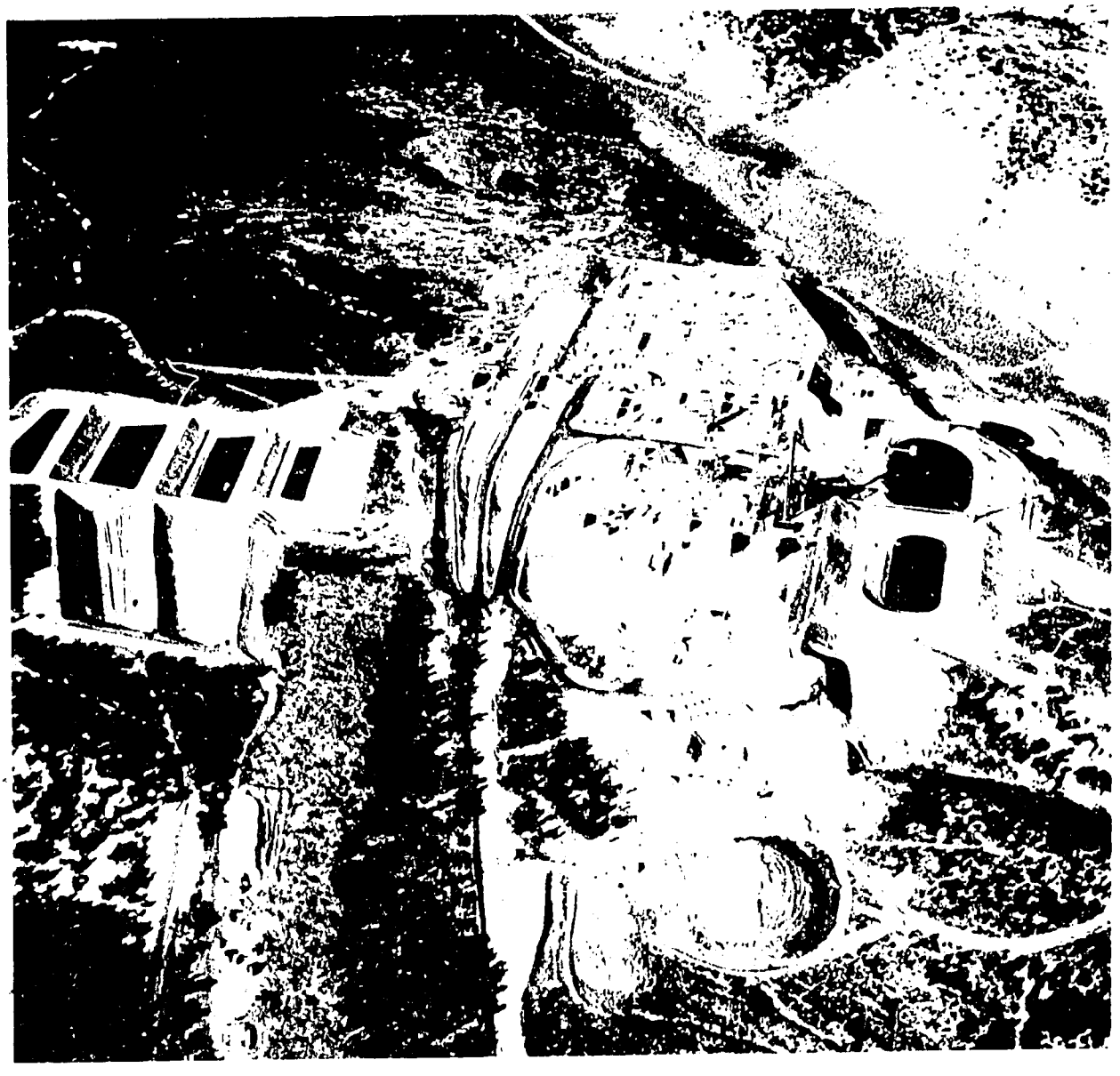
Resource Availability: Fair. Found in isolated areas where there may be significant water problems.

Fossil Fuel Displacement Potential: Good. Although not uniformly distributed, oil shale deposits are roughly equal to known resources of petroleum, and the refined products are middle-distillate fuels.

Cost Competitiveness with Fossil Fuel: Good. At present, the cost of fuel refined from shale oil exceeds the cost of other petroleum products, but the costs of oil shale derivatives are expected to become economically competitive by 1990.

Degree of Social Acceptability: Poor to Fair. An extensive program may be needed to mitigate the social impact of a massive influx of workers and capital to small communities in remote regions of the United States.

Environmental Acceptability: Poor to Fair. Air and water pollution may be serious problems with either in situ or above-ground retorting. Water demands



This demonstration project in northwestern Colorado is one of four tracts leased by the U.S. Government to develop oil shale facility prototypes.

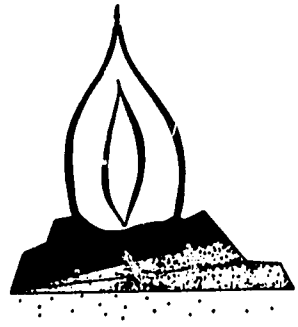
will be large and scenic land may be disrupted. Waste disposal problems exist for above-ground retorting.

Institutional Barriers to U.S. Commercialization: Many. Lengthy environmental reviews are required and most oil shale projects may require social impact analysis by Federal, state, and local governments.

Availability of Financing in the United States: Fair. Federal loan guarantees may be forthcoming. At present, lack of social and technological acceptance has limited investment.

Availability of Information in the United States: Fair. Most of the work performed by industry remains proprietary. The lack of commercial-scale plants means that technological and economic data is incomplete.

Chapter 11
Tar Sands



Introduction

Tar sands, oil sands, oil-impregnated rocks, bitumen-bearing rocks, and bituminous sands are interchangeable terms for consolidated or unconsolidated rocks — usually sandstone, limestone, or siltstone — containing a hydrocarbon material known as bitumen. Bitumen, a very viscous-to-solid form of crude petroleum that is not recoverable economically through a well, can be extracted from tar sands and treated, or upgraded, to a liquid "synthetic" crude oil. There is no definitive line separating a conventional oil field with a very viscous crude oil from a tar sands deposit with a slightly more viscous crude bitumen.

In the United States, substantial deposits of tar sands have been identified at about 550 locations in 22 states. U.S. deposits (primarily in California, Utah, Kentucky, New York, New Mexico, and Texas) are estimated to contain more than 36 billion barrels of oil. Utah deposits alone contain some 27 billion barrels of oil, of which four to five billion barrels are believed recoverable. The Utah sands yield about 40 kilograms of bitumen per metric ton of bitumen impregnated sands. While Utah tar sands deposits contain adequate resources to support a tar sands oil industry, they are not ideally suited for exploitation with current technologies. Most of Utah's deposits will require in situ recovery technologies.

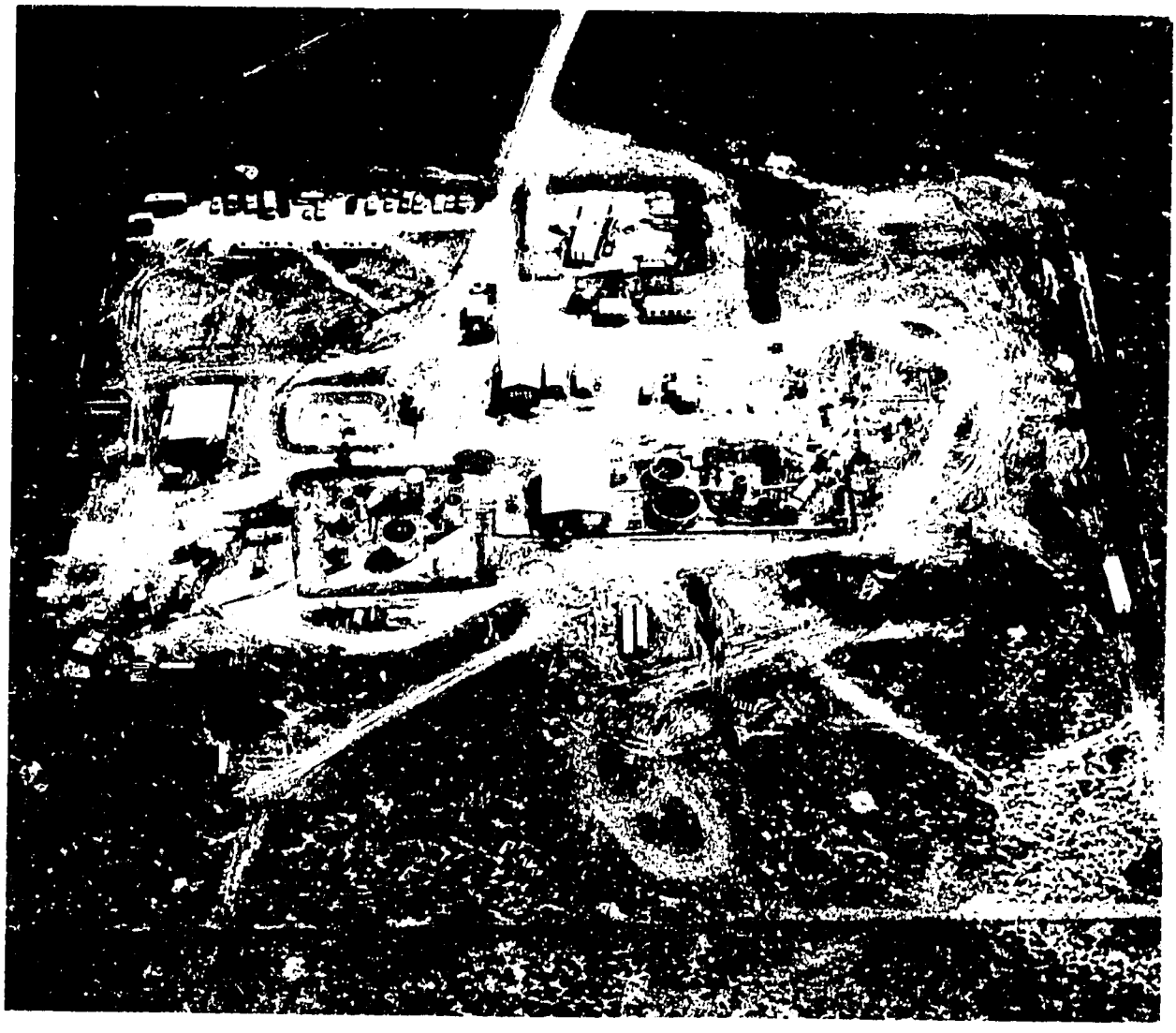
Internationally, Canadian tar sands operations, yielding more than 120,000 barrels of oil per day, are the world's largest. Venezuela, Romania, the USSR, Albania, Madagascar, and Trinidad also have significant tar sands deposits.

Tar sands bitumen can be recovered by either in situ or surface mining techniques. The most promising in situ techniques are steam drive and in situ combustion. Steam drive involves injecting steam into the formation to heat the oil, reducing its viscosity, and pushing it toward production wells. In situ combustion involves injecting air into the formation to maintain combustion. The resultant hot gases vaporize the lighter bitumen components and carry them to production wells. The coke deposit which is left behind serves as fuel for the advancing flame front.

Many techniques have been prepared for extracting the bitumen from mined tar sand ore. The three most promising are a modification of the Canadian hot water process, the use of solvents to displace the bitumen, and retorting. Surface mining is feasible in the United States for the 10 to 20 percent of all U.S. tar sands which do not lie deep underground.

Applications and Status

Synthetic crude oil obtained from extracting and upgrading bitumen can be used much like conventional crude oil—it can be refined into gasoline, jet fuels, and other petroleum products. Almost all efforts to extract energy from tar sands have been experimental, and most have been con-



Aerial view of a Department of Energy tar sand field experiment near Vernal, Utah. The site is approximately 4 hectares in size.

ducted by oil companies with at least some Federal funding. Some deposits have been exploited to obtain paving materials, and the less sandy tars have been converted into chemicals. In the mid-1970s, some Utah tar sands were processed in experimental plants, but no commercial operations have yet been established.

Developing U.S. tar sands will take time. In Utah, the existence of conventional oil and gas resources removes the urgency for extracting hydrocarbons from the state's large deposits of tar sands. Moreover, the nation's massive reserves of oil shale and coal dwarf the tar sands resource. Then too, the Canadian experience shows that it can take a decade to solve the technological and environmental problems associated with large-scale tar sands development. The U.S. activities will, of course, be speeded up because of the earlier Canadian development.

Economics

Unit production costs for fuels from tar sands are beginning to become available. However, they depend upon the type of deposit and recovery process used. Nonetheless, Canada's success in mining tar sands has given a boost to U.S. efforts,

raising the expectation that development of tar sands will eventually be cost-competitive with the production of other synthetic fuels.

Barriers and Impacts

The major barriers to tar sands development are technological and economic: the technology is still at an early stage of development, and the economic soundness of the technologies and the processes remains questionable. Environmental considerations associated with the disposal of waste products are also potential barriers to development. Water shortages in the area of known tar sands resources may be still another problem.

The social impact can be expected to increase as commercial operations begin. In particular, trying to attract qualified workers and professional personnel to sparsely populated areas where the tar sands are located could be difficult.

Private Activities

Industry interest is primarily focused on finding effective extraction and processing methods (especially for surface mining) and on patenting promising techniques. The capital provided by new government programs is expected to stimulate increased activity. A significant portion of the U.S. tar sands activity is directed by small companies.

Government Activities

The Department of Interior plans to lease Utah tar sands tracts to private industry in 1981. Details of the leasing program have yet to be announced, but environmental impact statements are being prepared for five areas, two of which will be leased.

The Department of Energy's tar sands program budget totals $12.7 million for the fiscal years 1979, 1980, and 1981. The main thrust of the program is to develop in situ recovery techniques that can be applied to the 80 percent of the U.S. resource that is too deep to surface mine. To date, three field tests have been conducted. Additionally, financial assistance is expected to become available through the U.S. Synthetic Fuels Corporation.

Projections

Commercial production goals for tar sands have been modest, since little experience has been accumulated with the technology and since the development of other energy sources is receiving higher priority. A tar sands operation in the United States capable of producing 80,000 to 120,000 barrels per day is possible by 1990.

Tar Sands in Brief

Present State of Development: Research and Development Stage. Much of the experience gained in Canadian operations is not transferable because of the differences in the physical composition of the tar sands.

Resource Availability: Fair. The economics of recovering U.S. tar sand reserves and water availability problems may limit U.S. production. Problems also remain in the leasing of Federal lands.

Fossil Fuel Displacement Potential: Fair. U.S. deposits are smaller than the nation's coal or oil shale deposits. However, the

A tar sand quarry operated by the road department of Uintah County, Utah.

composition of tar sands makes the removal of the oil relatively easier.

Cost-Competitiveness with Fossil Fuel: Fair. Although surface tar sand operations are being conducted in Canada, economic feasibility of large-scale in situ tar sand operations has not been established in the United States.

Degree of Social Acceptability: Fair. Regional and local concern with respect to tar sand development could be considerable. Problems are similar to oil shale development, but on a much smaller scale.

Environmental Acceptability: Fair. Problems related to ground water infiltration of in situ operations may lead to serious environmental problems in areas with nearby active aquifers.

Institutional Barriers to U.S. Commercialization: Some. Lengthy environmental and social impact reviews may result due to the large size of potential projects. These could, however, be less significant than for shale and coal projects, which are generally much larger.

Availability of Financing in United States: Fair. While Federal loan guarantees may be forthcoming, the technology has not been commercially demonstrated in the United States.

Availability of Information in the United States: Little. Since the composition of tar sand varies between sites and no commercial projects have been completed, the limited data that are available are not readily transferable.

Chapter 12
Further Information

Each of the preceding chapters provides only a summary of U.S. experience with and expectations from the technologies to be discussed at the August 1981 United Nations Conference on New and Renewable Sources of Energy. As a result of the rapid growth occurring in each technology area, this document can only provide a "snapshot" view, roughly accurate for early 1981.

It is not possible for any individual to stay current on all new and renewable energy technologies. Hundreds of specific and technical publications appear each month. Abstracts of the many research reports appear in the monthly **Solar Energy Update,** published by The Department of Energy's Technical Information Center.

Much of the information in this report was taken from U.S. Government program documents. These annual program documents will remain the best source for updating Federal activities for each technology. Information and statistical data about private sector activity is best obtained by reading the industry publications in each field. However, both the Energy Information Administration and the U.S. Department of Commerce are beginning to publish such data on a periodic basis.

Several periodicals cover the renewable energy technologies included in this paper. Those with the largest circulation are:

Solar Energy (International Solar Energy Society)
P.O. Box 52
Parkville, Victoria, Australia
305

SEIR (Solar Energy Intelligence Report)
Business Publishers
P.O. 1067
Silver Spring, MD 20910

Solar Times
3 Old Post Road
Madison, CT 06443

Solar Engineering
2636 Walnut Hill Lane
Suite 257
Dallas, TX 75229

Solar Age
P.O. Box 4934
Manchester, NH 03108

VITA News
VITA (Volunteers in Technical Assistance)
3706 Rhode Island Ave.
Mt. Rainier, MD 20822

Specific inquiries about renewable energy technologies may also be addressed to the Solar Energy Information Data Bank, SERI, 1617 Cole Blvd., Golden, CO 80401.

Monthly publications from the Energy Information Administration (for example **The Monthly Energy Review** available

from the Superintendent of Documents, Government Printing Office, Washington, DC 20402) provide the most authoritative statistics on all energy sources. The National Technical Information Service (NTIS) weekly publication **Energy** and the bimonthly **Energy Research Abstracts** are excellent regular indexes to publications in this broad field. (All NTIS publications are available from the National Technical Information Services, 5285 Port Royal Road, Springfield, VA 22161.) DOE's **Energy Insider** provides news items on activities within DOE (DOE mailstop 1E-218, Washington, DC 20585).

A semiannual publication, **Solar Collector Manufacturing Activity** [DOE/EIA-9174 (80/1)], is available from the National Technical Information Service for $2.25.

Further information sources are suggested in the following sections. Although conference proceedings are not as readily available as other sources, they are included since they provide the most current technical insight. The lists are abbreviated. Other U.S. and U.N. documents prepared for this conference deal with specific information sources. Inquiries about any material in this paper may be addressed to the UNCNRSE coordinator listed in the preface to this document.

Low-Temperature Solar

Recent Survey Books

Direct Use of the Sun's Energy. Farrington Daniels; New York, NY: Ballentine Books; 1964; 271 p. $1.95 (paper). Available from Random House, Inc., 400 Hahn Rd., Westminster, MD 21157. *Basic non-technical book on solar utilization, although now 17 years old. Covers all aspects of solar research and application.*

The Solar Home Book. Bruce Anderson and Michael Riordan; Andover, MA: Brick House Publishing Co.; 1976; 304 p. $13.95 (cloth)/$9.50 (paper). Available from Brick House Publishing Co., 3 Main St., Andover, MA 01810. *A practical book covering energy conservation, passive solar design, and active solar systems in a single, clearly written volume. Both large and small projects are discussed.*

The Passive Solar Energy Book. Edward Mazria; Emmaus, PA: Rodale Press; 1979; 435 p. $10.95 (paper). Available from Rodale Press, Inc., 33 E. Minor St., Emmaus, PA 18049. *A workbook discussing many passive solar energy designs. Widely respected as an excellent source of passive solar information.*

Periodicals

Solar Age. Monthly; 1976+; $20 per yr. Available from Solar Age, P.O. Box 4934, Manchester, NH 03108. *Provides information and news on low-temperature solar thermal energy. Official magazine for the American Section of the International Solar Energy Society (AS/ISES).*

Solar Engineering Magazine. Monthly; 1976+; $20 per yr. Available from Solar Engineering Publishers, Inc., 2636 Walnut Hill Lane, Suite 257, Dallas, TX 75229. *Covers spectrum of solar engineering with current events and evaluative articles, including solar thermal and industrial process heat technology.*

Conference Proceedings

AS/ISES 1980: Proceedings of the 1980 Annual Meeting. Gregory E. Franta and Barbara H. Glenn, eds. Phoenix, AZ; June 2-6, 1980; Newark, DE: American Section/International Solar Energy Society; 1530 p. (two volumes) $32.00 (plus $50.00 membership). Available from AS/ISES, 205B McDowell Hall, University of Delaware, Newark, DE 19711. *Several hundred papers at many levels of technical expertise covering all solar technologies, presented at the American Section of the International Solar Energy Society annual meeting. Many prior proceedings are also available.*

Solar Heating and Cooling Systems Operational Results. D. Ward, ed. Colorado Springs, CO; Nov. 27-30, 1979; SERI/TP-245-430; 358 p. $26.00 ($3.50 microfiche). Golden, CO: Solar Energy Research Institute. Available from NTIS. *Papers on actual operation of solar systems.*

Proceedings of the Fifth National Passive Solar Conference. Amherst, MA; Oct. 19-26, 1980; Newark, DE: American Section/International Solar Energy Society; 1400 p. (two volumes); $33 to members ($125 to non-members). Available from AS/ISES, 205B McDowell Hall, University of Delaware, Newark, DE 19711. *Covers all aspects of passive design. Prior proceedings also available.*

High- and Intermediate-Temperature Solar

Recent Survey Books

Description and Assessment of Large Solar Power Systems Technology. Compiled by L. N. Tallerico; Livermore, CA. Sandia Laboratories; SERI/SAND 79-8015; 158 p. $14.00 Available from NTIS. *Provides potential users with an overview of current technologies and those that will be available within the next few years. Summarizes the systems being developed by DOE's large solar thermal central power system program.*

An Overview Presentation of the U.S. DOE Solar Thermal Energy Systems Program. Gerald W. Braun; Golden, CO. Solar Energy Research Institute; SERI/SP-733-526; 1980; 39 p. $6.50. Available from NTIS. *Comprehensive overview of U.S. DOE's Solar Thermal Program. Cost goals, systems, design parameters, applications considerations, and potential for industry involvement in solar thermal development and commercialization are described in detail. Author directs the U.S. high-temperature solar thermal program.*

Periodicals

The Solar Thermal Report. Quarterly; 1980+; free. Available from SERI, 1617 Cole Blvd., Golden, CO 80401. *International communication for the solar thermal energy community.*

Solar Thermal Test Facilities Users Association. Quarterly; 1980+; $15.00 per year; available from STTFUA, Suite 1204, First National Bank Bldg. East, Central and San Mateo, N.E., Albuquerque, NM 87108. *Information on advances in high-temperature research, solar electric power generation and high-temperature solar testing facilities.*

Conference Proceedings

4th Semiannual Conference on Advanced Solar Thermal Technology Program. Phoenix, AZ; December 11-13, 1979; Pasadena, CA: Jet Propulsion Laboratory; SERI/TP-312-492; 142 p. free. Available in microfiche from SERI, 1617 Cole Blvd., Golden, CO 80401. *Abstracts presented in areas of systems applications and development, advanced components and subsystems, support activities, and solar materials.*

Proceedings of the National Conference on the Integration of Solar Energy into Utility System Planning and Strategies: 1980-2000. Topeka, KS; May 11-13, 1980. University of Kansas: Applied Research & Public Service Program; 278 p. $25.00. Available from University of Kansas Research Center, Inc., attention Robert F. Riorden, 2291 Irving Hill, Campus West, Lawrence, KS 66044. *Views and information from utility company attendees addressing questions the industry must face as they plan to meet the nation's energy needs.*

Photovoltaics

Recent Survey Books

Making and Using Electricity From the Sun. The Technical Staff of Solarex Corporation; Blue Ridge Summit, PA: Tab Books; 1979; 143 p. $5.95 (paper), $7.95 (cloth). Available from Tab Books, Inc., P.O. Box 40, Blue Ridge Summit, PA 17214. *Describes photovoltaics for the layperson, including the construction and use of solar cells.*

Solar Electricity: An Economic Approach to Solar Energy. Wolfgang Palz; Paris: UNESCO; 1978; 292 p. $51.75. Available from Unipub, 345 Park Avenue South, New York, NY 10010. *An introductory textbook of solar energy production, stressing physical and technological theory. Chapter 3 has a concise summary of photovoltaic conversion.*

Periodicals

Solar Cells: Their Science, Technology, Applications and Economics. Quarterly; 1979+; $97.00 per yr. Available from Elsevier Sequoia, S.A., Box 851, 1001 Lausanne 1, Switzerland. *Technical journal covers all aspects of photovoltaic research, applications, and systems analysis.*

The Solar Photovoltaics Monitor. Bimonthly; 1980+; $350 per yr. Available from MONEGON, LTD., 4 Professional Drive, Suite 130, Gaithersburg, MD 20760. *Provides information to professionals concerned with photovoltaics, addressing a broad range of interests in the field.*

Conference Proceedings

Photovoltaics Advanced R&D Annual Review Meeting. Denver, CO; September 17-19, 1979. Washington, DC: U.S. Government Printing Office; SERI/TP-311-428; 476 p. $33.50. Available from NTIS. *Technology-specific papers presented. Also includes a discussion of the Multi-Year Program Plan and R&D activities.*

Biomass

Recent Survey Books

Biological Paths to Self-Reliance: A Guide to Solar Energy Conversion. Russell E. Anderson; New York, NY: Van Nostrand Reinhold; 1979; 367 p. $21.95. Available from Van Nostrand Reinhold Co., Division of Litton Educational Publishing, Inc., Lepi Order Processing, 7625 Empire Drive, Florence, KY 41042. *A comprehensive treatment of biomass as an energy source.*

Biomass: Applications, Technology, and Production. Nicholas P. Cheremisinoff; Paul N. Cheremisinoff; Fred Ellerbusch; New York, NY: Marcel Dekker, Inc., 1980; 221 p. $29.50. Available from Marcel Dekker, Inc., 270 Madison Avenue, New York, NY 10016. *Discusses agricultural, silvicultural, and aquatic biomass as a source of energy. Includes lengthy bibliography.*

Energy From Biological Processes. Office of Technology Assessment; Washington, DC: U.S. Congress: Office of Technology Assessment; July 1980; Report No. OTA-E-124; 195 p. Available from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. Summary also available (same title, 23 p. Report no. OTA-E-123). *Presents analysis of prominent biomass issues, summaries of four biomass fuel cycles, a description of biomass' place in two plausible energy futures, and discussions of policy options for promoting energy from biomass in the*

United States. A second volume provides technical analyses of the resource base as well as information on conversion technologies and uses.

Energy to Biomass Option. H. R. Bungay, III; John Wiley Interscience, New York, NY. 1981; $29.95. *A comprehensive treatment of biomass energy option.*

Fuel Gas Production From Biomass. D. L. Wise ed.; Boca Raton, FL: CRC Press, Inc.; 1981; Vol. I $64.95, Vol. II $69.96. Available from CRC Press, Inc., 2000 NW 24th Street, Boca Raton, FL 33431. *This general book on anaerobic digestion has sections covering theory, worldwide activities, operation of pilot and full-scale systems, and engineering concepts and analysis.*

Fuels From Farms — A Guide to Small-Scale Ethanol Production. Golden, CO: Solar Energy Research Institute; 1980; SERI/SP-451-519; 157 p. $6.50. Available from The Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. *Covers basic ethanol production, feedstocks, plant design, a business plan, and worksheets to enable the reader to calculate factors affecting the decision to become a producer (such as markets, production potential, equipment selection, and financial requirements).*

A Guide to Commercial-Scale Ethanol Production. Golden, CO. Solar Energy Research Institute; 1980; SERI/SP-751-877; 300 p. $7.50. Available from The Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402 (Stock No. 061-000-00472-6). *Detailed information on business aspects of large-scale ethanol production including feedstocks, markets, financing, regulations, and plant design concepts.*

Periodicals

Bio-Joule 13. Bimonthly; 1978+; $10.00 per yr. Available from the Biomass Energy Institute, P.O. Box 129, Postal Station "C", Winnipeg, Manitoba, Canada R3M 3S7. *Newsletter covers use of biomass and biomass residues for production of fuels and energy.*

Biomass Digest. Monthly; 1979+; $87.00 per yr. Available from Technical Insights, Inc., P.O. Box 1304, Fort Lee, NJ 07024. *Newsletter covers use of biomass to produce energy and chemicals. Includes lists of patents, technical papers, and reports.*

Biotimes. Bimonthly; January 1979+; $10.00 per yr. Available from International Biomass Institute, 1522 K St., NW, Suite 600, Washington, DC 20005. *Newsletter devoted to research, education, and promotion of biomass applications in energy, farming, and other fields. Includes reports on alcohol fuels activities.*

Gasohol U.S.A. Monthly; June 1979+; $12.00 per yr. Available from Box 9547, Kansas City, MO 64133. *Trade journal covering production, marketing, and research related to gasohol. Provides articles, news bulletins, and advertising (for alcohol equipment and supplies) aimed at the generalist involved in the alcohol fuels movement.*

Conference Proceedings

Bioenergy 80 World Congress and Exposition; also Bioenergy Directory; Atlanta, GA; April 21-24, 1980. Washington, DC: Bioenergy Council; 586 p. $60.00 (Bioenergy Directory $70.00). Available from Bioenergy Council, 1625 I St. NW, Suite 825A, Washington, DC 20006. *Bioenergy 80 includes papers on all aspects of biomass; the directory is a project-by-project description of biomass projects throughout the world with emphasis on those in the United States.*

Energy From Biomass and Wastes IV. Lake Buena Vista, FL; January 21-25, 1980. Chicago, IL: Institute of Gas Technology; 834 p. $60.00. Available from Institute of Gas Technology, IIT Center, 3424 S. State St., Chicago, IL 60616. *Large number of papers covering all aspects of biomass and wastes. Annual conference.*

Third Annual Biomass Energy Systems Conference Proceedings: The National Biomass Program. Golden, CO; June 5-7, 1979; Golden, CO: Solar Energy Research Institute; October 1979; SERI/TP-33-285; 615 p. $41.00 ($3.50 microfiche). Available from NTIS. *Presents programs of DOE contractors in all areas of biomass.*

Wind Energy

Recent Survey Books

Wind Machines. Second Edition. Frank R. Eldridge; New York, NY: Van Nostrand Reinhold Company; 1980; 214 p. $17.95. Available from Van Nostrand Reinhold, 135 West 50th Street, New York, NY 10020. *This book provides an up-to-date look at wind energy and its applications, with many charts, photographs, and diagrams.*

Wind Energy. Tom Kovarik, Charles Pipher, John Hurst; New York, NY: Domus Books; 1979; 150 p. $6.95 (paper), $12.50 (cloth). Available from Quality Books, Inc., 400 Anthony Trail, Northbrook, IL 60062. *A general guide to wind system operation, storage, and conversion.*

Periodicals

Wind Energy Report: The International News Letter of Wind Power. Monthly; 1978+; $115.00 per yr. Available from Wind Energy Report, P.O. Box 14, Rockville Center, NY 11570. *Coverage includes meetings, ongoing wind programs, legislation, technological advances, and equipment.*

Wind Power Digest. Quarterly; 1974+; $6.00 per yr. Available from Jester Press, Route 2, Box 489, Bristol, IN 46507. *Surveys the wind energy field with general articles on new technology, activities, and legislation.*

Conference Proceedings

2nd Wind Energy Innovative Systems Conference. Colorado Springs, CO; December 3-5, 1980. SERI/CP-635-1061; Golden, CO: Solar Energy Research Institute. Available from NTIS. *Examines new ideas in the wind energy field.*

1980 American Wind Energy Association National Conference. Pittsburgh, PA; June 8-11, 1980. Washington, DC: American Wind Energy Association. 157 p. $25.00. Available from: American Wind Energy Association, 1609 Connecticut Avenue NW, Washington, DC 20009. *Presents all aspects of wind power.*

Ocean Systems

Recent Survey Books

Ocean Thermal Energy Conversion: Legal, Political, and Institutional Aspects. H. Gary Knight, J. D. Nyhart, Robert E. Stein, editors; Lexington, MA: Lexington Books; 1977; 243 p. $21.95. Available from Lexington Books, Division of O.C. Heath and Company, 125 Spring Street, Lexington, MA 02173. *Discusses legal and other non-technical issues involved in OTEC technology.*

Periodicals

Sea Technology. Monthly; 1960+; $15 per yr. Available from Compass Publications, Inc., Suite 1000, 1117 North 19th Street, Arlington, VA 22209. *Specializes in marine engineering; often has articles on OTEC developments.*

Solar Ocean Energy Liaison. Monthly; 1976+; $125 per yr. Available from Popular Products, Inc., 1303 South Michigan Avenue, Chicago, IL 60605. *Covers international developments in ocean energy. Especially good coverage of legislation and conferences.*

Conference Proceedings

Proceedings of the 6th Ocean Thermal Energy Conversion Conference. Washington, DC; June 19-22, 1979. Washington, DC: Ocean Systems Branch, Division of Central Solar Technologies, DOE; Various paging. $22. ($3.50 microfiche). Available from NTIS (CONF790631). *Proceedings of the major annual conference in ocean energy.*

Hydropower

Recent Survey Books

Report of the White House Interagency Task Force on Small Hydropower. Washington, DC: United States Department of Energy Assistant Secretary for Resource Applications; 1981; various paging; $11.00 bound ($3.50 microfiche). Available from NTIS (DOE/RA-0060). *A report that deals with the development of the United States' small hydropower resources.*

Hydroelectric Power Evaluation. Washington, DC: United States Department of Energy. Federal Energy Regulatory Commission, Office of Electric Power Regulation; 1979; 223 p. $5.50. Available from the Superintendent of Documents, Government Printing Office, Washington, DC 20402 (stock number 061-002-00030-8). *This report describes the process of evaluating a potential hydropower site in terms of the impacts and economics of its use.*

Reconnaissance Evaluation of Small Hydroelectric Installations. Tudor Engineering; San Francisco, CA: 1980; 407 p. free. Available from the Water and Power Resources Administration, mail code 922, Federal Center, Denver, CO 80225. *A methodology for assessing the economic viability of small hydropower facilities.*

Periodicals

Hydro-Wire. Bi-weekly; 1980+; $200 per year. Available from Hydro Consultants, Inc., P.O. Box 2321, Boston, MA 02107. *A newsletter addressing the needs of the small-scale hydroelectric industry.*

Small Hydro Bulletin. 3-5 times per year; 1979+; free. Available from the Hydropower Branch, United States Department of Energy, Idaho Operations Office, 550 Second Street, Idaho Falls, ID 83401. *This newsletter is prepared for DOE's Division of Hydroelectric Resources Development and is published when sufficient information has been accumulated.*

Conference Proceedings

Hydropower: A National Energy Resource, 1979 Engineering Foundation Conference. Easton, MO; March 11-16, 1979; The Engineering Foundation; 364 p. $6.50. Available from the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402. (Stock No. 008 022-001-00144-1.) *Concentrates on the utilization of the hydropower resource in the United States.*

Water Power - 1979 Conference Proceedings. Washington, DC; October 1-3, 1979; Corps of Engineers; various paging; $11.00. Available from the Superintendent of Documents, Government Printing Office, Washington, DC 20402 (Stock No. 008-022-00157-3). *This conference not only deals with conventional hydropower but with alternative technologies such as tidal power that rely on the movement of water.*

Geothermal Energy Systems

Recent Survey Books

Geothermal Energy Utilization. Howard F. Wahl; New York, NY: J. Wiley and Sons Publications; 1977; 303 p. $33.00. Available from: J. Wiley and Sons Publications, 1 Wiley Drive, Somerset, NJ 08873. *Describes the many uses of geothermal energy.*

Geothermal Energy As a Source of Electricity. Ronald DiPippo, Washington, DC; 1980; 370 p. $6.00. Available from the Superintendent of Documents, Government Printing Office, Washington, DC 20402 (stock number 061-000-00390-8). *This book describes the use of geothermal energy for electric power generation.*

Direct Utilization of Geothermal Energy; A Technical Handbook. Geothermal Resource Council; Davis, CA; 1980; 250 p. $10.00. Available from the Geothermal Resource Council, P. O. Box 98, Davis, CA 95616 (special report #7). *This book provides comprehensive information about most thermal applications of geothermal energy.*

Periodicals

Geothermal Energy Magazine. Monthly; 1973+; $50 per year. Available from: Geothermal World Corp., 18014 Sherman Way, Reseda, CA 91335. *This magazine reports recent developments in the application of geothermal energy.*

Geothermal Progress Monitor. Quarterly; 1979+; $11.00 per issue ($3.50 microfiche). Available from NTIS (OOE-RA-0051/4 is the most recent issue, #4). *This publication covers Federal activity in geothermal energy.*

Bulletin of the Geothermal Resource Council. Monthly; 1973+; $45 per year. Available from the Geothermal Resource Council, P. O. Box 98, Davis, CA 95616. *A regular membership ($45) entitles one to this bulletin and to discounts on GRC publications and conferences.*

Conference Proceedings

Geothermal Resource Council Annual Meeting. Salt Lake City, UT; September 9-11, 1980. Davis, CA, Geothermal Resource Council. 826 p. $28. Available from Geothermal Resource Council, P.O. Box 98, Davis, CA 95616. *This publication covers the annual meeting of the biggest geothermal energy trade organization.*

Proceedings of the Third Annual Geothermal Conference and Workshop. Monterey, CA; June 26, 1979. Santa Cruz, CA: Atlas Corp. 226 p. $18.50 (bound) $3.50 (microfiche). Available from NTIS (CONF-790679) *Papers and speeches presented at this conference.*

Oil Shale and Tar Sands

Recent Survey Books

Bitumens, Asphalts and Tar Sands. G. V. Chilingarion, T. F. Yen, editors; New York, NY: Elsevier Scientific Publishing Co.; 1978; 331 p. $78.00. Available from Elsevier Scientific Publishing Co., attention Customer Service, 52 Vanderbilt, New York, NY 10017. *Details the geology and chemistry of tar sands as well as information regarding oil extraction.*

Oil Shale and Tar Sands Technology. Ranner; Park Ridge, NJ: Noyes Data Corp., 1979; 430 p. $48.00. Available from Noyes Data Corp., Mill Road at Grand, Park Ridge, NJ 07656. *A general discussion of oil shale and tar sands.*

An Assessment of Oil Shale Technologies. Office of Technology Assessment; Washington DC: U.S. Government Printing Of-

fice; 1980; 517 p. $9.00. Available from: Superintendent of Documents, U. S. Government Printing Office, Washington, DC 20402 (Stock No. 052-003-00759-2). *A comprehensive, easily readable treatment of oil shale development and its impacts.*

The History of Western Oil Shale. Paul L. Russell; E. Brunswick, NJ: Center for Professional Advancement; 1980; 176 p. $49.50. Available from the Center for Professional Advancement, P. O. Box H, E. Brunswick, NJ 08816. *This book relates the history of oil shale development in the western United States.*

Periodicals

Shale Country. Monthly; 1975 +; $24.00 per year international, $10 per year United States and Canada. Available from Mountain Empire Publishing, 180 Cook Street (Suite 414) Denver, CO 80206. *This magazine discusses recent oil shale developments, especially in the western United States.*

Synfuels. Weekly; 1979+; $375 per year. Available from McGraw-Hill Inc., 1221 Avenue of the Americas, New York, NY, 10020. *Details the latest happenings in the area of synthetic fuels including oil shale.*

Conference Proceedings

Thirteenth Annual Oil Shale Symposium Proceedings. Golden, CO; April 16-18, 1980; Colorado School of Mines. 391 p. $16.00. Available from the Publications Office, Colorado School of Mines, 1500 Illinois Street, Golden, CO 80401. *Earlier proceedings are also available.*

Appendix A

NEW AND RENEWABLE TECHNOLOGY SUMMARY—IN BRIEF

	Solar Collectors: Low-Temperature Passive	Solar Collectors: Low-Temperature Active	Solar Collectors: Intermediate- and High-Temperature	Photovoltaics	Biomass Combustion	Biomass Conversion
Present State of Development Scale: R&D Stage Technically Ready Demonstration Stage Commercially Ready	**Commercially Ready** Techniques used for centuries; some lack of experience for new techniques; need for dissemination of design approaches and performance data.	**Demonstration Stage** Domestic water systems are commercially available. Space heating systems are being demonstrated but need cost reduction. Space cooling requires R&D and demonstration.	**Demonstration Stage** Central receiver systems and parabolic dish systems need demonstration. Parabolic trough systems are available commercially.	**Commercially Ready** For electrical needs in remote areas. Technically ready for residential electric applications with grid backup. R&D stage for utility use.	**Commercially Ready** Oldest known technology. Wood from nearby forests and aggregated, dry organic wastes are the most commercial. Experience in commercial operations is needed.	**Demonstration Stage** Anaerobic digesters chemical reduction, gasification, and liquefaction systems are developed. Smaller units are commercial; larger units need demonstration.
Resource/Raw Materials Availability Scale: Fair Good Very Good Excellent	**Excellent** All materials are conventional and readily available.	**Excellent** All materials are readily available.	**Good** No constraint on fabrication materials. Land availability may be a problem for industrial process heat.	**Excellent** Refining capacity for specific feedstocks will have to be increased but it is not a constraint.	**Excellent** Availability is regional but not a constraint.	**Excellent** Biomass can be produced on marginal lands; availability of water may be a limiting factor.
Fossil Fuel Displacement Potential (Year 2000) Scale: Fair Good Very Good Excellent	**Good** Heating of residential and commercial buildings requires a great deal of low-temperature heat. Passive systems can readily supply 50 to 100 percent of this required heat and save fossil fuels.	**Good** Potential displacement of electricity and oil for domestic water heating, space heating in buildings, and industrial process heat totals about 5 exajoules.	**Very Good** Systems are broadly applicable for process heat, electricity, and other industrial applications where fossil fuels provide much of the present power.	**Fair** Attractive in dispersed applications but displacement is not large.	**Very Good** Fossil fuel displacement is significant in the near-term.	**Excellent** Land-based and aquatic production offer a large resource base. Organic residues, from many sources provide an early economic energy source.
Cost-Competitiveness with Fossil Fuels (Year 1990) Scale: Fair Good Very Good Excellent	**Excellent** Some techniques require little additional cost, others require modest increases. Passive systems are very competitive with fossil fuels.	**Good** Water heating is competitive with electricity and oil in most regions of the U.S. Space heating is near-economic for northern regions. Space cooling is not economic.	**Good** Industrial process heat systems reducing use of electricity and oil can be competitive first in the Southwestern U.S. Solar electric systems augmenting existing oil-fired utility plants show early economic viability in the Southwest.	**Good** Competitive in remote electric markets. Prices need to decline by a factor of about 10 for grid-connected residential applications.	**Excellent** Competitive with fossil fuels, but assurance of long-term supply is a concern.	**Good** Ethyl alcohol from grains is now used in gasohol, which is competitive as a motor fuel. Anaerobic digestion of animal wastes is economic for rural uses. Gasifiers are near economic. Various liquefacation processes need cost reduction.
Degree of Social Acceptability Scale: Poor Fair Good Very Good Excellent	**Excellent** With appropriate designs, passive system components can be integrated aesthetically into a building.	**Excellent** Most systems can be aesthetically integrated into building structure.	**Good** Rural land areas covered by large collector fields are expected to be acceptable in selected arid areas in the Southwest. Areas adjacent to urban and secnic areas are expected to be very limited.	**Excellent** Systems produce electricity, which is well understood and widely accepted by consumers. There is little noise for home installation and system reliability is well established.	**Excellent** Aesthetically pleasing in home-heating; accepted practice in industry.	**Excellent** Gasohol is being accepted readily. Use of wastes for energy is appealing while reducing environmental impacts. Use of surplus farm products for energy is generally being endorsed. Increasing use of marginal crop lands is attractive.

NEW AND RENEWABLE TECHNOLOGY SUMMARY—IN BRIEF (CONTINUED)

	Solar Collectors: Low-Temperature Passive	Solar Collectors: Low-Temperature Active	Solar Collectors: Intermediate- and High-Temperature	Photovoltaics	Biomass Combustion	Biomass Conversion
Environmental Acceptability Scale: Poor Good Very Good Excellent	**Excellent** There are some potential concerns with indoor air pollution arising from close control of building air exchange.	**Excellent** There are minor problems in handling some waste products.	**Good** Some minor concerns exist regarding potential harm to desert environment.	**Excellent** Some minor concerns in manufacture. Generally, a very clean approach to power generation.	**Very Good** Particulate emissions and carbon dioxide may pose a problem.	**Good** Issues of land use, depletion of soil, erosion, and air pollution are of concern.
Institutional Barriers to U.S. Commercialization Scale: None Few Moderate Many	**Few** Some resistance to modifying building codes; solar access legislation may be required.	**Few** Some modifications needed in building codes and solar access legislation. Many barriers have already been substantially resolved.	**Few** Regulations, land use and use of large reflective surfaces may pose some barriers.	**Few** Cost is a severe problem for other than remote electric applications. In addition, use in residential applications requires resolution of fire and safety building codes.	**Few** An industry structure needs to be developed for the collection and transportation of biomass.	**Few** There are persistent questions of competition between food and energy uses of biomass. Large land commitments for energy farming are required. Questions are being raised about net energy savings in production and use of biomass crops for fuels.
Availability of Financing in the United States Scale: Little Fair Good Very Good Excellent	**Excellent** Private investment is available as costs are small.	**Good** Substantial tax credits (40%) are available. First-cost financing is a continuing problem. Financing of domestic water heating systems is most easily obtained.	**Fair** Large capital investment and long payback hampers financing for process heat. Utilities require demonstration of reliability.	**Fair** Remote electric applications are economical with Federal and state tax credits. Large price reductions are required for widespread use in residential and utility applications.	**Excellent** Financing available where resources are adequate.	**Fair** Some Federal investment credit and loan guarantees are available but technology demonstrations are needed. Tax credits for homeowners and small system users are available.
Availability of Information in the United States Scale: Little Fair Good Very Good Excellent	**Good** Data on optimum designs are not readily available. Information on general approaches and system performance is available. Consumers and builders are not well informed about the potential benefits.	**Good** Detailed information on lifetime, reliability, costs and design details is available. Consumers are not well informed about selection, installation, and maintenance of systems.	**Fair** Parabolic trough data on performance and cost are available. Other systems need pilot system demonstration.	**Good** Lifetime, reliability, and cost data are available from domestic and international applications. Consumers are not well informed about potential uses.	**Very Good** Data are available through state and local organizations.	**Fair** Need further cost and performance data validation. Consumers need more education in the potential of these systems.

NEW AND RENEWABLE TECHNOLOGY SUMMARY—IN BRIEF (CONTINUED)

	Wind	Ocean	Hydropower	Geothermal	Oil Shale	Tar Sands
Present State of Development Scale: R&D State Technically Ready Demonstration Stage Commercially Ready	**Demonstration Stage** Large systems being demonstrated at several sites; small systems are commercial.	**Technically Ready** Mini-OTEC and OTEC-1 experiments have been successfully deployed on the open ocean. Technology is now ready for a pilot plant development project.	**Commercially Ready** Mature technology. Small hydro needs some engineering and industrial development.	**Commercially Ready** About 800 MW_e of geothermal power from dry steam wells in the U.S. Hotwater power plants are in the demonstration stage. Dry-hot-rock plants are in the R&D stage.	**Demonstration Stage** Engineering problems must be solved for modified in situ processes and above ground retorting.	**R&D Stage** Tar sands deposits in the U.S. are deeper than in Canada, may require in situ extraction.
Resource/Raw Materials Availability Scale: Fair Good Very Good Excellent	**Excellent** All materials and required resources are available.	**Good** Titanium production capacity expansion may be necessary; use of alternative materials may overcome this problem.	**Very Good** Construction material available locally; equipment requires lead time of one year or longer.	**Fair** Equipment requires special corrosion-resistant materials.	**Fair** Found in isolated areas where there may be significant water problems	**Fair** Water availability may be a problem.
Fossil Fuel Displacement Potential (Year 2000) Scale: Fair Good Very Good Excellent	**Good** Wind resource regional and site-specific. Good potential for displacement in regions with most prevalent need, e.g., Northeast.	**Small** Commercial deployment by the early 1990s will be in tropical islands; but overall displacement is relatively small.	**Good** Expansion of existing large hydropower is limited, but use of small hydro could result in significant displacement.	**Fair** Although large in some areas, not highly significant from U.S. perspective, lack of experience in optimum rate of utilization.	**Good** Very large deposits, not uniformly distributed; meets transport fuel needs.	**Fair** U.S. deposits are nominal; removal of oil and raw material handling is difficult.
Cost-Competitiveness With Fossil Fuels (Year 1990) Scale: Fair Good Very Good Excellent	**Very Good** Small machines are economical in farm and rural applications. Utility applications will become competitive by 1990.	**Fair** Cost competitive in early markets that are oil dependent; power for U.S. mainland may be competitive in the late 1990s.	**Excellent** Extremely cost-effective in view of increasing fuel costs; marginal sites now economical.	**Good** Competitive where resource is abundant and high quality.	**Good** Costs are expected to be competitive when commercial plants begin operation.	**Fair** No data on economic feasibility of in situ operation.
Degree of Social Acceptability Scale: Poor Fair Good Very Good Excellent	**Very Good** Locating wind machines away from urban areas will mitigate problems of noise and television interference.	**Good** Off-shore operation presents no problems for urban areas; enhanced employment for fishing industry.	**Good** Precedents are well established; social issues are known and understood.	**Fair** Noise, brine and effluent disposal, and odor of hydrogen sulfide may not be acceptable if not controlled.	**Poor to Fair** Boomtown effect on small communities, large influx of workers and capital.	**Fair** Regional and local concerns similar to oil shale.

NEW AND RENEWABLE TECHNOLOGY SUMMARY—IN BRIEF (CONTINUED)

	Wind	Ocean	Hydropower	Geothermal	Oil Shale	Tar Sands
Environmental Acceptability Scale: Poor Fair Good Very Good Excellent	**Excellent** Minimal impact on air and water quality, and wildlife.	**Excellent** Some minor issues raised about possible changes in ocean ecology.	**Very Good** Some concerns of plant and animal life disruption, risk of dam failure.	**Good** Environmental impacts can be controlled.	**Poor to Fair** Air and water pollution problems; disruption of scenic land; disposal of waste materials.	**Fair** Environmental problems due to contamination of ground water by infiltration.
Institutional Barriers to U.S. Commercialization Scale: None Few Moderate Many	**Few** Federal legislation requiring utilities to sell and buy back power at equitable rates from residential and commercial users who have installed acceptable solar systems. Aesthetic considerations in urban areas may restrict commercialization.	**Moderate** Legal issues exist regarding legal jurisdiction, insurance, and operation of OTEC plants.	**Few** Hydropower is closely regulated; regulatory burdens are being eased for small hydro.	**Moderate** Will require environmental review for commercial plants; utility rate structure may be a problem for hydrothermal.	**Many** Lengthy environmental and societal impact reviews by Federal, state and local governments.	**Some** Large projects result in lengthy environmental and social impact reviews.
Availability of Financing in the United States Scale: Little Fair Good Very Good Excellent	**Very Good** Access to capital should not be difficult due to cost-effectiveness.	**Little** Large capital requirement and risks require demonstration of pilot plant, some government assistance may be available for early units.	**Very Good** Capital available for private and public projects; small hydro special investment tax credits are available.	**Good** Dependable and uninterruptible source can be developed in stages.	**Fair** Limited investment due to technological and social acceptance; loan guarantees available.	**Fair** Private investment will require demonstration; some Federal loan guarantees may be available.
Availability of Information in the United States Scale: Little Fair Good Very Good Excellent	**Very Good** Performance data on commercially available machines are being accumulated now. Data on large utility-scale prototypes are being obtained from current tests.	**Fair** Cost, performance, and resource data are available from early experiments, but pilot plant operational data needed.	**Excellent** Design construction procedures and costs are well documented and readily available.	**Very Good** Resource and technology information is available and is being distributed.	**Fair** Industry work remains proprietary; incomplete technical and economic data.	**Little** Data availability is limited due to deeper deposit and varying composition between sites.

Appendix B
Glossary

Active solar system. Any solar system that needs mechanical means such as motors, pumps, or valves to operate.

Agricultural and Industrial Process Heat (AIPH). Both an end-use application for thermal energy and the name applied to that portion of the U.S. solar program developing solar technologies for agriculture and industry (see IPH).

Anaerobic digestion. The process of using microorganisms that live only in the absence of oxygen to decompose organic materials into more valuable or more easily disposed of components. The chief use of anaerobic digestion is reduction of the volume of sewage sludge. It can also be used for the production of synthetic natural gas from organic wastes or from algae.

Array. (As in thermal or electrical solar array.) Several solar-collection devices interconnected in groups and in patterns.

Baseload plant (Baseload electricity). An electrical generation facility that is designed primarily to satisfy a continuous demand. Generally, capacity factors of baseload plants range from 60 percent to 90 percent.

Biofouling. The growth of small marine organisms that can decrease the heat transfer efficiency of heat exchangers used in seawater in ocean thermal energy conversion systems.

Biomass. Defined in the Energy Security Act (PL96-294) as "any organic matter which is available on a renewable basis, including agricultural crops and agricultural wastes and residues, wood and wood wastes and residues, animal wastes, municipal wastes, and aquatic plants.

British thermal unit (Btu). The amount of heat required to raise the temperature of one pound of water one degree Fahrenheit under stated conditions of pressure and temperature. (The Btu is equal to 252 calories, 778 foot-pounds, 1055 joules, and 0.293 watt-hours.) It is a standard unit in the United States for measuring quantity of heat energy.

Capacity factor. The ratio of the amount of electricity produced by a plant or system to its maximum theoretical productive capacity.

Capital-intensive. Requiring heavy capital investment. The energy industry, for example, is said to be capital-intensive rather than labor-intensive.

Closed-cycle ocean thermal energy conversion. A form of ocean thermal energy conversion (OTEC) using a working fluid (such as ammonia or propane) that can be vaporized by warm ocean surface waters and condensed with cool ocean waters, and recycled continuously in a closed loop.

Collector efficiency. The fraction of incoming solar radiation captured by the collector. For example, if the system captures half of the incoming radiation, the system is said to be 50 percent efficient. Efficiency is the capability of a collector to capture heat under various climatic conditions. There is no way a collector can be 100 percent efficient, that is, capture all the heat that falls on the collector; 55 percent is good under desirable weather conditions.

Concentrating collectors. Solar collectors designed to focus large amounts of solar radiation on a relatively small collection area to produce higher temperatures than those attainable by flat-plate collectors.

Conduction. The transfer of heat through matter by the movement of kinetic energy from particle to particle rather than by a flow of heated material; it also defines the way in which electricity travels through a wire or the way heat moves from a warm body to a cool one when the two bodies are placed in contact.

Convection. The transfer of heat by means of the upward motion of the particles of a liquid or a gas that is heated from beneath; transmission of heat by moving masses of air.

Conversion efficiency. The actual net output provided by a conversion device divided by the gross input required to produce the output.

Conversion system. A device or process that converts a raw energy form into another, more useful form of energy. Examples: conversion of wood into methanol or of sunlight into electricity.

Decentralized systems. In solar systems, complete, independent units of energy production to serve households, neighborhoods, villages, or factories, which are not dependent on other energy delivery grids.

Demand. The rate at which energy is delivered to or by a system expressed in kilowatts, kilovolt-amperes, or other suitable units, at a given instant or averaged over any designated period of time. The amount of energy required to satisfy the needs of a stated sector of the economy.

Department of Energy (DOE). In October 1977, the Department of Energy (DOE) was created to consolidate the multitude of energy-oriented government programs and agencies. The Federal Energy Administration and the Energy Research and Development Administration are now part of DOE. The Department is carrying out the National Energy Plan policy through a unified organization that coordinates and manages energy conservation, supply development, information collection and analysis, regulation, research, development, and demonstration. An Energy Information Administration within the Department organizes and analyze information so that it can be used by governments, industry, and the public.

Department of Housing and Urban Development (HUD). A U.S. Federal agency; responsible for most residential solar heating and cooling demonstration programs.

Diffuse insolation. The scattered solar power density (watts per square meter) falling on a surface from the sky, and, in the case of an inclined surface, reflected onto it from the ground as well; it does not include direct insolation. (See total insolation.)

Digester. A device in which anaerobic bacteria decompose organic matter to produce methane and carbon dioxide.

Direct insolation. The solar power density (watts per square meter) from the sun falling on a surface.

Distributed system. Used synonymously with decentralized system. (See definition.)

Domestic Policy Review (DPR). A cabinet-level, multi-agency review of the national solar energy program, initiated by the President on May 3, 1978, with results announced June 20, 1979.

Efficiency. The efficiency of an energy conversion is the ratio of the useful work or energy output to the work or energy input. For electrical generators, it is that percentage of the total energy

content of a power plant's fuel which is converted into electricity, the remaining energy being lost to the environment as heat.

Energy Extension Service. A Government program to encourage the use of energy conservation and alternative energy technologies at the state and local levels. The program focuses primarily on homeowners, small businesses, public institutions, and state and local governments. The Service is similar to the USDA extension service.

Energy farm. A concept involving the cultivation of rapidly growing trees or other selected plants for the purpose of providing biomass that can be used as a fuel or converted into other energy products.

Ethanol. Ethyl alcohol or grain alcohol, C_2H_5OH. It is the alcohol contained in intoxicating beverages. Ethanol can be produced from biomass by the conversion process called fermentation and can be used as a motor fuel.

Eutectic salts. A chemical that has the property of changing from a solid to a liquid while maintaining a constant temperature. The heat energy that caused the transformation is stored in the eutectic liquid until the liquid returns to solid form and gives up heat. In application, eutectic salts are used as thermal reservoirs to conserve and then to release solar heat.

Evacuated tube collector. A collector designed to keep heat loss at a minimum. It is manufactured from concentric glass tubes with a vacuum between the tubes. These collectors are highly efficient at relatively high (about 100°C) temperatures.

Exajoule (EJ). A standard metric unit of energy equal to 10^{18} joules. One exajoule equals 0.948 quads. (See quads and joule.)

Feedstock. Material used for its chemical properties, rather than their value as fuel, e.g., oil used to produce plastics and synthetic fabrics. Also raw material that can be converted to one or more end-products (methanol or synthetic natural gas, for example). Biomass is an energy feedstock.

Fermentation. The process of decomposition of carbohydrates with the evolution of carbon dioxide or the formation of acid, or both.

Fiscal year (FY). U.S. Government's 12-month financial year, from October through September of the following calendar year; for example, FY 1978 extends from October 1977 through September 1978.

Flat-plate collector. A device for gathering the sun's heat, consisting of a shallow (usually metal) box with a glass or transparent plastic lid, where either air or liquid is circulated through the cavity of the box. The sun's energy is absorbed on a "black" plate and the entire box is insulated on the bottom and edges.

Fresnel lens and mirror. Used in solar concentrator devices to focus sunlight on solar cells in converting solar energy into electricity. The lens or mirror consists of stepped surfaces, allowing a thin design.

Fuel saver. A solar device used solely to save fuel at conventional fossil fuel-burning facilities. The conventional systems provide the needed system reliability.

Gasohol. A blend of alcohol and gasoline, typically 10 percent agriculturally derived ethanol and 90 percent unleaded gasoline.

Gasifier. A vessel in which gasification takes place.

Geothermal energy. The heat energy available in the rocks, hot water, and steam in the earth's subsurface.

Gigawatt. Power unit equal to one billion (10^9) watts, one million kilowatts, or one thousand megawatts.

Greenhouse effect. The heating effect of the atmosphere upon the earth. Light waves from the sun pass through the air and are absorbed by the earth. The earth then reradiates this energy as heat waves that are absorbed by the carbon dioxide in the air which behaves like glass in a greenhouse, allowing the passage of light but not of heat. Many scientists theorize that an increase in the atmospheric concentration of carbon dioxide can eventually cause an increase in the earth's surface temperature.

Head. The differential of pressure causing flow in a fluid system, usually expressed in terms of the height of a liquid column that the pressure will support.

Heat exchanger. A device that transfers heat from one fluid (liquid or gas) to another, or to the environment.

Heat pump. A reversible heating and cooling mechanism that can produce additional usable heat from the amount stored, such as a mechanical refrigeration system which is used for air cooling in the summer and which, when the evaporator and condenser effects are reversed, can absorb heat from the outside air or water in the winter and raise it to a higher potential so that it can also be used for winter heating.

Heliostat. A device that contains a mirror moved by a control mechanism to reflect the light of the sun in a particular direction.

High-head. Refers to generation of hydropower using large dams (compare, low-head).

Hybrid solar system. Solar energy systems that combine both direct thermal (passive) and indirect solar design elements and equipment into one system; for example, solar collectors on a roof providing heat to the direct thermal storage component located inside the insulated shell of the structure.

Hydropower (Hydroelectricity). Power produced by falling water.

Hydrostorage. Use of a dam to store energy: water is pumped into a reservoir and released when power needs to be generated.

Industrial Process Heat (IPH). The end-use applications of thermal energy (at a wide range of temperatures) in industry. The term is also used to indicate that portion of the U.S. national solar program that deals with this end-use. (See AIPH.)

In situ. In the natural or original position or location. In situ production of oil shale, for instance, is an experimental technique in which a region of shale is drilled, fractured, and set on fire. The volatile gases burn off, the oil vaporizes, then condenses and collects at the bottom of the region from which it can be recovered by a well.

Insolation. The rate at which energy reaches the earth's surface from the sun. Usually measured in Btu per square foot per day or joules per square meter per day.

International Solar Energy Society (ISES). The principal, non-governmental worldwide organization for exchanging information on all forms of solar energy.

Joule (J). The meter-kilogram-second (mks) unit of work or energy. It equals 1 watt-second or 10^7 ergs, or approximately 0.7375 foot-pound, or 0.2390 gram-calorie.

Kilowatt (kW). A unit of power equal to 1,000 watts or to energy consumption at a rate of 1,000 joules per second. It is usually used for electrical power. An electric motor rated at one horsepower uses electrical energy at a rate of about 3/4 kilowatt.

Kilowatt-hour (kWh). The unit of energy equal to that expended in one hour at a rate of 1 kilowatt; or 3,413 Btu.

Life-cycle cost. The total costs for the purchase, installation, operation, and maintenance of a system over its useful life. The accumulation generally includes a discounting of future costs to reflect the relative value of money over time.

Line-focusing collector. A mirror system, usually consisting of a parabolic trough, that concentrates the incident solar radiation on a line where it can be converted to useful energy. (See point-focusing collector.)

Low-head. Refers to generation of hydropower with relatively small dams (approximately 30 megawatts or less). (Compare, high-head hydropower.)

Megawatt (MW). A unit of power. A megawatt equals 1000 kilowatts, or one million watts.

Methane. A colorless, odorless, flammable, gaseous hydrocarbon that is a product of the decomposition of organic matter. It is used as a fuel and as a raw material in chemical synthesis. The chemical formula is CH_4. CH_4 is the prime constituent of natural gas. Methane is made by certain biomass conversion processes.

Methanol. A light, volatile, flammable, poisonous, liquid alcohol, CH_3OH, formed in the destructive distillation of wood or made synthetically and used especially as a fuel, a solvent, an antifreeze, or a denaturant for ethyl alcohol, and in the synthesis of other chemicals. Methanol can be produced as fuel for motor vehicles.

MBtu (often MMBtu). Million Btu's (British thermal units).

Module. The smallest, complete assembly of solar cells, optics, and other components designed to generate DC power.

Ocean thermal energy conversion (OTEC). Process of using the warm ocean water (ocean's sun-heated top layer) to vaporize a working fluid to run a turbine to produce electricity.

Off-peak service. The period during a day, week, month, or year when the load being delivered by an energy system is not at or near the maximum volume delivered by that system for the corresponding period of time.

Oil shale. A very fine-grained sedimentary rock that contains enough organic matter (hydrocarbon) to yield 10 gallons or more oil per ton when properly processed. Some shales yield much more oil, and in the United States some thin layers of shale have been reported to yield 140 gallons of oil per ton. Most shales that are of commercial interest yield from 25 to 65 gallons of oil per ton. Some foreign deposits that contain shales yielding between 10 and 25 gallons per ton have been mined on a large scale. Many other organic-rich shales yield less oil (1 to 10 gallons per ton), but these shales are so low grade that they usually are not called "oil shale."

Open-cycle ocean thermal energy conversion. (See closed-cycle ocean thermal energy conversion.) In open-cycle OTEC systems, the working fluid is ocean water that is vaporized.

Parabolic collector. A device for collecting the sun's energy that utilizes a bowl-shaped reflector. The reflector, which is mirrored, concentrates the radiation, producing temperatures as high as 1649°C.

Parabolic dish. A parabola-shaped device covered with a mirrored surface that focuses sunlight at a single point; used in solar concentrators with concentration ratios typically from 1,000 to 10,000.

Passive solar system. A system that uses gravity, heat flows, or evaporation to operate without mechanical devices to collect and transfer energy, such as sun-facing windows.

Payback period. A traditional measure of economic viability of investment projects. For energy projects, a pay-back period is defined in several ways—one of which is the number of years required to accumulate fuel savings equal to the capital cost of the system. (See life-cycle cost.)

Peak watt (W_p). A unit of measure used in rating the performance of photovoltaic panels and arrays. A panel rated at 1 peak watt will deliver 1 watt under specific standard noontime operating conditions (including a solar insolation of 1 kilowatt per square meter).

Phase change. The physical transformation of a substance from one state—solid, liquid, or gaseous—to another. Associated with such a change of state is a large absorption or release of energy known as the heat of fusion or vaporization.

Photosynthesis. The process in plants by which carbohydrates are compounded from carbon dioxide and water in the presence of sunlight and chlorophyll. Photosynthesis is the primary method of bioconversion of solar energy into forms more useful to society.

Photovoltaic cell. A type of semiconductor in which the absorption of light energy creates a separation of electrical charges. The separation creates an electrical potential. The net effect is direct conversion of light into electricity. Typical materials used in the construction of photovoltiac cells are silicon, cadmium sulfide, and gallium arsenide.

Photovoltaic process. Process of converting light rays directly into electricity without going through intermediate steps involving turbines and generators. In photovoltaics, solar cells convert sunlight into a stream of electrons easily converted into household current.

Point-focusing collector. Any mirror or system of mirrors or lenses that concentrates sunlight on a point.

Power tower. A tower placed so that the reflected direct radiation from heliostat mirrors can be focused onto a receiver at its top. Heat exchange takes place at the receiver on the tower, and the heated fluid is used in a conventional power system.

Primary energy. Energy in its naturally occurring form (coal, oil, uranium) before conversion to end-use forms.

Process heat. Heat that is used in agricultural and industrial operations.

Pyrolysis. Decomposition by the action of heat; thermal decomposition of organic compounds in the absence of oxygen.

Quad. One quadrillion (10^{15} or 1,000,000,000,000,000) Btu.

Rankine engine. A reversible heat engine.

Receiver. The solar thermal component of a solar concentrator system. A receiver is designed to operate under concentrated sunlight and to absorb thermal energy.

Renewable resources. Sources of energy that are regenerative or virtually inexhaustible, such as solar, wind, ocean, biomass and hydropower energy. Geothermal energy is sometimes also included in the term.

Retrofit. The installation of equipment subsequent to the completion of initial construction, such as the installation of solar collectors and other hardware onto an existing house to convert it for solar heating.

Roof pond. A passive solar collection system in which plastic bags of water on the roof are appropriately exposed or insulated during the day and night, depending on the thermal requirements of the building for summer and winter operation. Heat transfer (into or out of the bags) to the structure is directly through the ceiling.

Semiconductor. A crystal system in which, though the electrons are ionically bound, a slight rise in temperature frees the valence atoms so that the system becomes a conductor; an example is germanium.

Shale oil. A crude oil obtained from bituminous shales by submitting them to destructive distillation in special retorts.

Silviculture. The technology of raising trees, or forest management.

Solar cell. A device which converts radiant energy directly into electric energy by the photovoltiac process. Each cell produces a small potential difference, typically about 0.5 volts; an array of cells can provide a useful electric power capacity.

Solar collector. A device used to gather and accumulate the sun's energy or solar radiation. Nearly all non-concentrating collectors have a layer of glass on top (some have plastic) to trap the heat once it passes into the collector. The medium used to transfer the heat to the rest of the system varies. Another type of collector, the focusing collector, employs a concave mirror turned by a motor to follow the sun as the earth moves. The basic function of the solar collector is to capture the sun's heat.

Solar constant. The average amount of solar radiation reaching the earth's atmosphere per minute. The solar constant is measured on a plane perpendicular to the path of the radiation. Its value is 1.36 kilowatts per square meter (or 430 Btu per square foot per hour).

Solar energy. The energy transmitted from the sun in the form of electromagnetic radiation. Although the earth receives about one-half of one billionth of the total solar energy output, this amounts to about 420 trillion kilowatt-hours annually.

Solar Energy Research Institute. The Solar Energy Research, Development and Demonstration Act of 1974 called for the establishment of a Solar Energy Research Institute whose general mission would be to support the nation's solar energy program and foster the widespread use of all aspects of solar technology, including direct solar conversion (photovoltaics), solar heating and cooling, solar thermal power generation, wind energy conversion, ocean thermal conversion, and biomass conversion.

Solar pond. A pond with a blackened base containing (stratified) brackish water or insulation that is used to collect and store solar heat.

Solar Power Satellite (SPS). A proposed satellite that would be put into stationary orbit above the earth to convert solar energy to electricity and then to microwave (or possibly laser) energy, to be beamed to earth for conversion back to direct and then alternating current electricity.

Solar rights. Continued access to sunlight for installed solar systems.

Solar power thermal conversion systems. Thermal conversion systems involving an extensive array of pipes heated by the sun's rays. In one concept, nitrogen flowing through the pipes would gather the heat and transport it to molten salt. The molten salt can be heated to a temperature of about 538 °C for production of steam, which would power conventional turbines at a projected efficiency of about 30 percent. The area required to supply energy to a 1000-megawatt power plant would be about 10 square miles of collection surface; a 300,000-gallon reservoir of molten salt for energy storage would be necessary for nights and cloudy days.

Solar total energy system (STES). Solar total energy systems use the sun's heat to generate electricity and the leftover or residual heat for other purposes. Several technical approaches are being investigated as applicable to STES. These include small central receivers, distributed collectors, and photovoltaics.

South wall. See Trombe wall. This would be termed a "North wall" in the southern hemisphere.

Stirling hot-air engine. The Stirling engine can use solar energy or can burn any type of fuel to generate the heat used in the engine. Like the internal combustion engine, the Stirling has a cylinder and pistons. However, the solar energy is directed to the outer walls or the fuel is burned outside of the cylinder (external combustion). The heat is used to expand a gas in the cylinder, which pushes down on the piston to produce the power stroke. Problems that remain to be solved include the handling of the very large quantity of waste heat which must be removed by the radiator and the need for heater heads which can contain the high-temperature and high-pressure gas.

Synthetic natural gas (SNG). A gaseous fuel manufactured from coal or biomass, containing almost pure methane, CH_4, and produced by a number of gasification schemes. SNG contains 95 percent to 98 percent methane, and has an energy content of 980 Btu to 1035 Btu per standard cubic foot, about the same as that of natural gas.

Tar sands. Sand impregnated with petroleum that has turned to viscous or solid bitumen; hydrocarbon-bearing deposits distinguished from more conventional oil and gas reservoirs by the high viscosity of the hydrocarbon, which is not recoverable in its natural state through a well by ordinary oil production methods.

Tennessee Valley Authority (TVA). A large Federal electric power agency that is also a major purchaser of renewable energy systems and active in renewable energy experiments.

Terawatt (TW). Power unit equal to 10^{12} watts or one million megawatts.

Thermal conversion. The transformation of heat into other forms of energy such as electricity or shaft power. Heat may be supplied from the sun either directly (solar collector) or indirectly (ocean systems or biomass).

Thermal mass. Also thermal inertia. The tendency of a building or components with large quantities of heavy materials to change temperature very slowly; also, the overall heat-storage capacity of a building.

Thermosiphon. The principle that makes water circulate automatically between a solar collector and a storage tank above it, gradually increasing its temperature. A solar heating system that uses natural convection to transport heat from the collector to storage by appropriately locating the storage in relation to the collector.

Total energy system (TES). A packaged energy system of high efficiency, utilizing solar energy or gas-fired turbines or engines that produce electrical energy and utilize exhaust heat in applications such as heating and cooling. (See also solar total energy systems).

Total insolation. The sum of direct and diffuse insolation.

Trombe wall. A passive solar heating system that combines the solar collector and heat storage in one, sun-facing wall unit. The system consists of a thick concrete wall painted black on its outer face. Sheets of glass are placed in front of this wall with an airspace between. Air from the rooms of the building passes through openings at the foot of the wall and enters the airspace where it is heated by the sun. As it warms, the air rises up the air cavity by natural convection, and passes back into the building interior again through a second series of openings at the top of the wall. In order to arrest the flow of warm air into the building in summer, the openings in the wall are blocked by shutters.

Wind energy conversion system (WECS). A wide variety of machines have been designed to convert wind energy into useful power. The large-scale systems currently being developed most often utilize a horizontal axis design: any design will require siting in high average wind speed areas.

Appendix C
Acronyms

AID	Agency for International Development, the principal U.S. bilateral development assistance agency
AIPH	Agricultural and Industrial Process Heat
bbl	Barrels (of oil). One barrel equals 42 American gallons, 306 pounds, 5.6 cubic feet. The heat content is approximately 5.8×10^6 Btu/bbl.
Btu	British thermal unit (See Glossary)
DOE	Department of Energy (See Glossary)
DPR	Domestic Policy Review (See Glossary)
EJ	Exajoule, 10^{18} or one billion billion joules (See Glossary)
EPA	Environmental Protection Agency
FERC	Federal Energy Regulatory Commission
FY	Fiscal Year (See Glossary)
GJ	Gigajoule, 10^9 or one billion joules
GNP	Gross National Product
IPH	Industrial Process Heat (See Glossary)
ISES	International Solar Energy Society (See Glossary)
kW	Kilowatt (See Glossary)
kWh	Kilowatt-hour (See Glossary)
MBtu	Million (10^6) British thermal units (See Glossary)
MJ	Megajoule, 10^6 or one million joules
MW	Megawatt, a unit of power equal to 10^6 watts
MWh	Megawatt-hour, a unit of energy, equal to 10^6 watt-hours
NASA	National Aeronautics and Space Administration, active in several solar technology areas, has the major U.S. responsibility for the SPS (Solar Power Satellite)
NSF	National Science Foundation, the lead Federal agency for solar energy research and development until 1975
OTEC	Ocean Thermal Energy Conversion (See Glossary)
PURPA	Public Utilities Regulatory Policy Act
R&D	Research and Development
RD&D	Research, Development and Demonstration
SERI	Solar Energy Research Institute (See Glossary)
SHAC	Solar Heating and Cooling (See Glossary)
SPS	Solar Power Satellite or Space Power Systems; also sometimes used to refer to Small Power Systems (See Glossary)
STES	Solar Total Energy System (See Glossary)
TES	Total Energy System (See Glossary)
TVA	Tennessee Valley Authority (See Glossary)
TW	Terawatt (See Glossary)
USDA	United States Department of Agriculture, often termed DOA (responsible for several parts of the national solar program)
WECS	Wind Energy Conversion Systems (See Glossary)
W_p	Peak watt (See Glossary)

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