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INDUSTRY COMMENT LETTER:
ENERGY DEVELOPMENTS

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SOLAR ENERGY OPPORTUNITIES

The rising costs and uncertain availability of conventional energy sources have led to increased interest in solar energy options as a means of helping to meet future energy demands. The importance of these options will increase as the required developments proceed and as conventional sources and other alternatives are found to present potential problems in terms of resource conservation, public health, international trade and politics, environmental protection, and social equity.

Industry is taking initiatives to develop products and provide services in several important solar energy application areas. These activities will increasingly be reinforced by government support of research and development and sponsorship of demonstration projects. At present, the funds allocated to these activities by the government are still only a small percentage of the total federal energy R&D budget, but successful demonstration of solar energy applications should lead to significant increases in the funding levels.

The initial commercial opportunity in solar energy will be in the heating and cooling of residential and commercial buildings. This market has a potential value of over $1 billion by 1985. Longer-range potential exists in power plants run on solar heat, wind, or ocean thermal gradients; direct conversion of solar energy to electricity; and use of solar energy to grow renewable fuels.

Introduction

Government and industry groups in many countries are investigating a number of concepts for harnessing solar energy. Several U.S. companies are beginning to commit significant resources to new solar energy-related activities, and government funding of solar energy research has increased dramatically over the last three years, reaching about $50 million in fiscal 1975. A bill providing $60 million for demonstration projects for solar-heated and cooled buildings over five years was passed in September, and a $1 billion across-the-board program for solar energy research and development over five years was enacted by Congress in October. In addition, Japan has announced its Project Sunshine, for which multibillion dollar expenditures are being planned over the next 25 years; Australia is planning an expanded solar energy program; similar efforts are under way in Western Europe; and the Soviet Union is continuing to pursue a significant solar energy development program.

The degree to which solar energy applications can be successfully moved beyond the research and development phase will depend upon the availability and nature of competing alternative energy sources and the cost/benefit trade-offs required to arrive at a coherent energy policy. Solar energy is abundant enough to provide self-sufficiency and clean enough to meet the most stringent environmental standards. The challenge lies in finding methods for converting this energy efficiently and economically into useful forms.

The amount of energy the United States land area receives annually from the sun is some 500 times as much as the energy consumption projected for the year 2000. One square yard of land exposed to direct sunlight receives the energy equivalent of about 1 horsepower. However, solar energy is not easily convertible and is not "free." It can be considered a widely distributed resource somewhat akin to low-grade mineral deposits. The collection and conversion of solar energy into useful forms must be carried out over a large area, entailing significant capital investment for the conversion apparatus. In addition, since solar energy is not constantly available on Earth, some form of storage is needed to sustain a solar-powered system through the night and during periods when local weather conditions obscure the sun. This storage capacity involves an additional capital cost.

The widespread use of devices that utilize solar energy will require considerable development to strike the appropriate balance between technology, the environment, and society's needs. Results are unlikely to come about quickly, not because of the lack of advanced technology, but rather because of too little industrial experience with such technology. The nation lacks both the capacity to mass-produce systems at a cost low enough to create a large market and also the institutional arrangements needed for the rapid introduction of solar-powered systems. The government has an important role to play in developing and demonstrating solar energy on a commercial scale; establishing a central source of standards and research literature; aggregating the market among federal agencies; identifying and reducing institutional barriers at the federal, state, and local levels; and developing legal concepts to define and protect "sun rights."

Concurrent with successful demonstrations, both producers and consumers must be encouraged to take the next logical steps toward developing a mass market through selected and effective subsidy programs. Government policy designed to protect proprietary rights would greatly increase industrial participation. Above all, before making major investments, industry needs to be assured that government policy will remain consistent as the market for solar technology develops.

The potential payoff of research and development in solar energy applications has been recognized and such R&D is now being supported on a significant scale. It is thus becoming increasingly realistic to assess several of the options for solar energy conversion.

Heating and Cooling

The most promising near-term application for solar energy is in the heating and cooling of buildings. About 90 buildings in the United States already include solar heating systems, and solar hot water heaters are in wide use in Japan, Australia, Russia, and Israel. Several demonstration projects are in various stages of completion: several schools have been equipped to use the sun's energy for a portion of their hot water, heating, and cooling needs, and systems in public buildings, office buildings, and residences in many locations will shortly provide information on the degree of success achieved in solar-heated and cooled buildings.

A typical solar heating and cooling system includes the following components:

- **Solar Collector** – a means of capturing solar thermal radiation in an enclosure with a glass or plastic cover. Since the cover is transparent to the incident solar radiation, but opaque to the re-radiated energy, the solar collector, like a greenhouse, serves to trap solar energy and turn it into heat.

- **Heat Storage System** – a material that has a high specific heat or experiences a change of phase. It accepts collected solar heat as available and allows it to be withdrawn as needed.

- **Source of Auxiliary Energy** – fuel or electricity to provide heat during extended cloudy periods and to avoid the need for uneconomically large collection and storage facilities.

- **Heat-actuated Air Conditioner** – a unit that can be driven by the collected solar heat.

- **Auxiliary Equipment** – the piping, controls, heat exchangers, heat transfer fluid, valves, pumps, motors, and other equipment needed to couple the essential elements to an operating system.

These systems can be integrated into buildings designed for efficient thermal control through the choice of appropriate insulating materials for windows, roofs, and floors without sacrificing aesthetic architectural design.

Major innovations take considerable time to be introduced into the housing industry and to be accepted by the builder and buyer. However, several factors favor the application of solar energy to provide hot water, heating, and cooling in buildings:

- rapidly rising fuel costs;

- energy conservation measures;

- industrialization and increased sophistication of the construction industry;
- public pressure for environmental quality; and
- government actions supporting development of solar-energy applications.

The basic economic case for substituting solar energy for conventional energy sources rests on the desirability of substituting capital for nonrenewable fuels. The capital costs of installed solar equipment are largely attributable to labor utilized in the production of the equipment and components and in the installation of the equipment. The financial burden and the materials and energy used in building the solar equipment present themselves clearly at the time of the initial installation. However, once installed, solar equipment provides cost savings over the many years of its operation. Moreover, a comparison of the costs of solar and conventional systems does not adequately reflect the hidden costs – environmental, social, or political – which are not now charged against the conventional fuels. As broader-based cost accounting is adopted, the cost benefits of solar heating and cooling of buildings will become increasingly favorable as compared with those of competing fuels. In addition, the effects of lessening the reliance on imported fuels will lead to a more favorable trade balance.

The annual capital charges for the solar equipment range from $300 to $600 for typical residences – expressed as the additional mortgage payments over a ten-year period attributable to the incremental cost of the solar equipment. At this level solar heating and cooling could now be competitive with conventional systems, particularly with electric resistance heating. Heating and cooling costs can be minimized when solar energy accounts for approximately 50% of the total heating or cooling load. Beyond this level, the increased capital investment for the solar equipment tends not to be effectively utilized.

Industry has indicated that it can develop products based on present technology and that it has the capacity to supply the required resources and equipment. Arthur D. Little, Inc., has brought together in one project 90 industrial organizations from around the world that could make a solar heating and cooling industry a reality. The objectives of this project are to define the technology base, establish market prospects and economic projections, and provide the data on which product development and business decisions can be based. An industry based on this near-term solar application not only could be profitable to those contributing to it, but also would provide an important means of reducing consumption of nonrenewable energy resources.

The market for solar heating, cooling, and hot water will depend on the prices and availability of competitive fuels, government policies, and the effectiveness of manufacturing and marketing strategies. About 20% of the present national energy consumption is accounted for by household and commercial uses. Theoretically, up to 75% of the energy for these purposes could be provided by solar energy. We estimate the potential market for solar climate control at over $1 billion by 1985.

The environmental benefits of this use of solar energy are measured by the environmental damages caused by the fuel replaced. Damage to the environment by solar equipment operation is virtually inconsequential compared to any of the conventional fuels: such use of solar energy does not cause air, water, or thermal pollution; it does not require solid waste disposal, fuel storage, pipelines, transmission lines, or other forms of fuel transportation; and it does not create potential hazards. Furthermore, use of solar equipment reduces land use of the total energy supply system as it is installed primarily on building roofs.

Power Plants

Heat Engines

The prospect of focusing the sun's energy to generate steam for a power plant has long been intriguing. A solar-powered steam engine, using a large mirror to focus solar radiation on a boiler, was the central attraction of the 1878 Paris World Exposition. Similar plants were built in California in 1901 and in Egypt in 1913.

Large-scale terrestrial solar power plants have been proposed to work in conjunction with conventional power plants – in Russia about 15 years ago and more recently by researchers at the University of Arizona and the University of Houston. Several design approaches for solar-energy-concentrating mirrors and thermal storage devices are now being investigated by Honeywell, General Atomic, and others under contract to the National Science Foundation. In one approach, arrays of linear parabolic sun-tracking mirrors would focus solar radiation onto heat-absorbing tubes. These tubes, coated with a solar radiation-absorbing material, were designed to heat to about 1000°F a circulating fluid which would transfer the heat to a thermal storage system. Alternatively, heat pipes could be used to transfer the heat from the tubes to the thermal storage area. The heat would be withdrawn from storage during cloudy days and at night and transferred to a working fluid, which would drive turbine generators to produce electricity.

To overcome the heat losses associated with collecting the heat from a large number of parabolic mirrors, an alternative approach is being investigated by several aerospace firms. In this method, mirrors focus sunlight onto a central boiler placed on top of a tall tower, producing temperatures of 1000°F. A one-square-mile mirror field and a 1500-ft tower would be needed to provide a useful power output of 100 Mw. Such power plants, incorporating six hours of energy storage, are projected by the National Science Foundation to have a capital cost of $1000/kw in 1974 dollars. Much engineering remains to be done to identify optimum system parameters, evaluate specific component designs and energy storage approaches, and establish the economics of various systems to decide on the specifics of a pilot plant.

If these ongoing investigations are successful, a 5-Mw demonstration plant is expected to begin construction during the next five years at a cost of $25 million, funded by NSF, and if these are shown to be successful, a large-scale power plant will be produced by 1985. Plants of this type could also be part of total energy systems delivering both heat and electricity for residential and commercial uses.

These approaches work at their design efficiency only on clear days, indicating that the choice of suitable locations will favor the desert areas of the Southwest. The environmental impacts of solar heat-engine power plants are related primarily to land use, the effects of shading predominantly desert areas, and induced demographic pattern changes.

Wind Energy

Solar energy is also available indirectly through the winds, since solar energy sustains the winds. Of the average solar energy reaching the Earth – 1 kw per square meter of surface area – 2-20 watts per square meter are converted into kinetic energy. Winds are remarkably repeatable and predictable, and the moving air can be extracted by wind generators installed in suitable locations. A wind power system could incorporate an energy storage system: for example, the electricity produced and not used directly could be used for the electrolysis of water to produce hydrogen for transmission through pipelines as an alternative fuel.

The theoretical power potential in the winds over the continental United States and within 200 miles of its shores exceeds, by a factor of at least ten, projected U.S. electricity demand in the year 2000. A practical goal would be to supply 5% of the electrical energy demand by wind power (this would exceed the contribution of hydroelectric power plants).

In 1915, wind power was used to generate 100 Mw of electricity in Denmark. In the 1940's, an 1100-kw machine was operated experimentally in Vermont. Buildup of ice during a winter storm resulted in failure of the blades. Wartime scarcity of material did not permit replacement of the blades.

A wind generator requires a minimal wind speed of about 10 mph in order to produce power. Wind velocity increases logarithmically with height above ground; the structures to support efficient wind generators would have to be more than 100 ft high, raising the cost of the system and also presenting aesthetic problems for use in populated areas.

Where the winds are moderate to strong, large machines are most economic, but substantial advances in the design of very lightweight airfoils at Princeton University (being proved by Grumman Aerospace Corp.) indicate that small-scale wind power generation also may be feasible. The typical sizes for a wind generator can range from 20 kw to about 2 Mw.

There are no critical technical feasibility problems in the design of wind generators. The major questions are associated with the degree to which cost reductions can be made and uncertainties eliminated. The National Science Foundation is sponsoring studies and experiments at NASA Lewis Research Center to reduce these uncertainties. Present estimates are that wind generators, without energy storage and located in the prairie states, in the Lake Ontario region, and in upper Michigan, will cost $500-700/kw, rendering them competitive with other remote power-generation methods.

The land use for wind generators is comparable to that of fossil fuel plants. No significant adverse environmental impacts are expected beyond the aesthetic effects noted. Alternatively, wind generators could be located about 100 miles off the Atlantic coast, where wind conditions are excellent and there is a huge continental shelf to which floating generators could be anchored. The power could be delivered to shore by cable, or sea water could be electrolyzed to produce hydrogen for pipeline delivery, assuming such methods would not result in undesirable environmental effects.

Ocean Thermal Gradients

The temperature difference between the sun-heated upper layer of ocean water and the cold deeper water offers another opportunity for indirect use of solar energy. This temperature difference can be used to power very large heat engines. The concept of using the sun-heated ocean was first put forth in the early 1900's. Experimental power plants were built in 1929 off the coast of Cuba and in 1956 off the coast of Africa. These plants failed because of design limitations and, in the case of the Cuban plant, damage by a hurricane.

The National Science Foundation is sponsoring research programs to explore several design concepts and cost parameters for plants of 100 Mw or larger. Hundreds of specially designed platforms (with a generating capacity of 500 Mw each) could be anchored in the Gulf Stream to extract this energy. The warm surface waters would be passed through heat exchangers which boil a fluid such as propane or ammonia to drive huge turbines coupled to generators. The cold water pumped from the ocean depth (about 3000 ft) would be circulated through heat exchangers to condense the working fluid. The process would require heat engines that would operate over a temperature difference of about 40°F, for which a feasible system efficiency would be about 2%. The major challenge would be to develop very effective heat exchangers and to design the large turbines to extract energy from the working fluid. In addition, the materials would have to be able to withstand the effects of seawater for prolonged periods and be kept free of marine growths. No significant environmental effects of this energy generation method have yet been identified.

Direct Conversion

Solar energy can be converted directly to electricity by means of solar cells (photovoltaic conversion). In contrast to thermodynamic conversion, photovoltaic conversion involves no moving parts, circulating fluid, or consumption of material. Furthermore, a solar cell can operate for long periods without maintenance.

The first successful silicon solar cell was demonstrated in 1953 at Bell Telephone Laboratories. Today, silicon solar cells are a necessary part of the power supply systems of most spacecraft. As a result of space programs, there is now a substantial technological base for further developments. The two primary research goals are increased efficiency and lower costs. Efficiencies of 16% have been obtained at Comsat laboratories. The theoretical maximum for a silicon solar cell is 23%.

Silicon solar cells presently cost about \$20,000/kw. With further expansion of the markets for unattended packaged power supplies – e.g., communication equipment, navigational aids, and signaling devices – costs are projected to drop to about \$5,000/kw over the next several years. New techniques for the production of single-crystal silicon as achieved in the continuous ribbon process by Tyco Laboratories (being commercialized in a joint venture 80% owned by Mobil Oil) and automated assembly of solar cells being studied by NASA and NSF could reduce prices to less than \$1,000/kw over the next 10 years. Once a large enough market has opened up to justify major investments in the production machinery, the cost of silicon solar cells could decline to as little as five times the cost of plate glass (sand is the basic raw material for both products).

Several other solar cell materials are under development. A modified gallium arsenide solar cell researched by IBM has resulted in an efficiency of 18%. Today, gallium is expensive, but it is as abundant as lead and is available from the slag piles of aluminum smelters. There is promise that it can be developed as an alternative solar cell material, particularly for use in spacecraft. Copper oxide-cadmium sulfide thin-film cells which are being investigated at the University of Delaware represent another possibility. Although the efficiency of these cells is less than 7%, they can be produced by vacuum deposition, which is projected to lower production costs relative to silicon crystal cells.

Solar cells could be used in combination with a solar collector to supplement electricity requirements of a building. Large installations of concentrating mirrors combined with solar cells could lead to low-cost direct solar-energy conversion systems. For example, one square mile of land (e.g., desert area) covered with such devices that have an efficiency of 10% could generate 180 Mw when the sun shines. Such large installations could have significant impacts on land-use patterns and future demography. Shading of areas by solar energy collecting surfaces could affect the ecology, particularly in desert areas.

Terrestrial conversion systems suffer from the diffuseness and irregular availability of sunlight, which require them to have large solar energy collecting areas and some form of energy storage (e.g., water pumped to an elevated reservoir, compressed air, electrical storage batteries, or a system to produce hydrogen by electrolysis of water). Consequently, solar energy conversion systems able to generate power on a substantial scale will be economical only in a limited number of geographical locations.

Such Earth-bound obstacles can be overcome by locating the conversion systems in outer space where solar energy is constant. One approach for the continuous conversion of solar energy is to place a satellite solar power station in synchronous orbit 22,300 miles from the Earth's equator. Solar collectors would convert solar energy directly to electricity, which would be fed to microwave generators incorporated in a transmitting antenna. The antenna would direct a microwave beam to a receiving antenna on Earth, where the microwave energy would be converted back to electricity. (The microwave power density within the beam is so low that microwave levels beyond the receiving antenna can meet the severest international standards for exposure to continuous microwave radiation.) Microwaves can be converted directly to d.c. electricity with an efficiency of 85%. This very high conversion efficiency greatly reduces the undesirable effects of thermal pollution associated with all known thermodynamic processes for power production.

The absence of gravitational forces and of the active environmental influences present on Earth permits the deployment in space of very large lightweight solar collector structures which could not be installed on Earth. Because of the continuous availability of solar energy in synchronous orbit, only about 10% of the area of solar cells necessary to achieve the equivalent power output on Earth would be required. Furthermore, there would be no requirement for energy storage. Such a satellite could be designed to generate 3,000-20,000 Mw of electrical power on Earth. A system of satellites maintained in stationary orbital locations could deliver power to various geographic locations, with the receiving antenna placed either on land or on platforms over water near major load centers.

A space transportation system based on a second-generation space shuttle/space tug combination would be used to orbit the satellite, probably not before 1990. The capital cost of a 750-Mw prototype satellite, including the orbital and ground-based systems, space transportation, and assembly, is projected to be $1500/kw in 1974 dollars. The energy payback period for system components and space transportation propellants is on the order of one year. Further cost reductions for larger-output satellites could be achieved by advanced space transportation systems.

The feasibility of such a satellite solar power station was assessed by a group of companies (Arthur D. Little, Inc., Grumman Aerospace Corp., Raytheon Co., and Textron, Inc.) with partial support from NASA. This feasibility assessment indicates that this concept is worthy of consideration as an alternative energy production method, and that it could be cost competitive with other advanced energy production systems. A preliminary assessment of environmental impacts – such as troposphere and stratosphere pollution from space transportation system exhaust products; microwave effects on plants, birds, and aircraft; and radio frequency interference – indicates that these could be controlled and reduced to acceptable levels.

On a recent demonstration carried out by Raytheon at the Goldstone antenna site in California, a microwave beam was transmitted across one mile and converted directly to electricity with 75% efficiency. Within six months, an efficiency of 80% is expected to be achieved with microwave beams of about 15 kw. A pilot experiment could be performed in orbit in less than 10 years. Using state-of-the-art technology, a prototype satellite could be demonstrated in the early 1990's and a commercial system could come on line before the year 2000.

Production of Renewable Fuels

Fossil fuels originated millions of years ago as the result of solar energy-induced photosynthesis. To supplement fossil-fuel deposits, photosynthesis could be used to produce organic materials such as plants or trees that could then be converted to clean gaseous, liquid, and solid fuels by pyrolysis or similar processes. One ton of dry organic material could yield about 10,000 cu ft of methane gas or 2 bbl of fuel oil. With a 2% photosynthetic conversion efficiency and good growing conditions, one acre could produce 20 tons/year of organic materials. Although some investigations along these lines are under way, we expect considerably more time to be required before this approach could be commercialized.

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