

Schematic outline of vertical aqueduct system. It is hoped, will have to eventually be built in a second phase will mesh the manufacture project with fresh-water production. A plant is visualized in which the sea deep-ocean water is pumped via large diameter pipes through a condenser located on shore to intercept the flow of highly humid maritime air masses which are characteristic of certain tropical areas. This air, when cooled, condenses moisture, which is then conducted away and stored for use as a potable water supply. The ocean water only slightly warmed in the process is then conducted to the phytoplankton-producing lagoons, which in turn drain back to the sea. The third element in the project, the production of electric power, may employ from a power plant, heat exchanged with the deep-sea water on the cold side and with the warm humid air on the warm side. In this way the "condenser" for atmospheric water recovery could be the "boiler" for the power generating system [1]. Other uses for the cold water may include air conditioning and freezing applications. The cold water is also being considered for the improvement of conventional desalination processes and for the cooling of nuclear reactors.

References
 1. Daniels, Donald E., "Heat and Power from Sea Water," The Proceedings of Marine Research, Vol. 1, National Institute of Oceanography, Manila, 1968.
 2. Daniels, Donald E., "Energy from the Tropical Seas," ASME Transactions, Vol. 80, 1968, pp. 1048-1054.
 3. Daniels, Donald E., and Bore, G. A., "Deep Ocean Water as a Heat Source," Journal of Marine Technology, Vol. 1, No. 2, 1972, pp. 10-17.
 4. Daniels, Donald E., and Bore, G. A., "Deep Ocean Water as a Heat Source," ASME Transactions, Vol. 80, No. 2, 1968, pp. 1048-1054.
 5. Daniels, Donald E., and Bore, G. A., "Deep Ocean Water as a Heat Source," ASME Transactions, Vol. 80, No. 2, 1968, pp. 1048-1054.
 6. Daniels, Donald E., and Bore, G. A., "Deep Ocean Water as a Heat Source," ASME Transactions, Vol. 80, No. 2, 1968, pp. 1048-1054.
 7. Daniels, Donald E., and Bore, G. A., "Deep Ocean Water as a Heat Source," ASME Transactions, Vol. 80, No. 2, 1968, pp. 1048-1054.
 8. Daniels, Donald E., and Bore, G. A., "Deep Ocean Water as a Heat Source," ASME Transactions, Vol. 80, No. 2, 1968, pp. 1048-1054.
 9. Daniels, Donald E., and Bore, G. A., "Deep Ocean Water as a Heat Source," ASME Transactions, Vol. 80, No. 2, 1968, pp. 1048-1054.
 10. Daniels, Donald E., and Bore, G. A., "Deep Ocean Water as a Heat Source," ASME Transactions, Vol. 80, No. 2, 1968, pp. 1048-1054.

of the pattern on a most ingenious design wherein an exchanger acting as the boiler is to be located in a depth of 2500 ft and the plant condenser is located to a depth of 100 ft. Turbine and other components are at intermediate "depths" of the atmosphere. Presumably any such thermodynamic system is not in itself a novel idea, but it will be novel to the sea at the respective depths, to maintain a steady balance. During winter, the water will be pumped out of all parts as the sun goes on stream. It has been suggested by Ottner [1] that other thermodynamic exchangers may be designed to compensate for the large pressure difference on the two sides so that only the cold-water section can be lowered going down to the depths. Support for the large mass of heat-exchange surface and the reduction of exchanger temperature drop may be many heat interchanging, the Anderson's system could achieve major advantages in economy of reasonable size and cost, and the elimination of vacuum and desalination problems. Economically, the Anderson's multiple no-jumper difficulties. Studies made a few years ago [2] show investment per kilowatt in a fuel-free plant, such as a solar tower, should not exceed that for a 300-MW fuel-fired plant. The curves plotted (page 25) for the levels of fuel cost versus annual load factors indicate that a sea thermal plant costing less than \$250/kwh should be competitive with a fuel-fired plant. Other studies made more recently by the Anderson's indicate the cost per kilowatt even lower, \$100/kwh comparing sea thermal with hydro. Two facts are noted by the Anderson's: A sea thermal plant of average size would handle about the same amount of water as a hydro facility. As for cost of equipment, it is a bit high but not escape unmentioned. Dams, penstocks, and turbines are also expensive.

Project Sea Grant
 Cold ocean water deep below tropic seas is one of the world's resources. In fact it may be the most abundant. And used in conjunction with warm surface water, it makes available an infinite pool of potential energy. Roughly 70 percent of the earth's surface is covered with water, most of which is more than 3000 ft in depth. Project Sea Grant [3] is an experiment to tap this resource for the production of electric heat and power (see sidebar). If successful, the project would stand as proof that technology can be harnessed to the natural environment with minimal impact. The first phase of the operation is to obtain water at 2500 ft from a depth of 2500 ft. The location of the water with steep offshore slopes is ideal for the purpose. In that area, the deep-water temperature is 41 F (5 C), while the surface water ranges from 81 F (27 C). The cold deep-ocean water, far richer in phosphate than surface water, will be brought to the surface through a 3.5-ft-dia pipeline to a warm-water lagoon. Here it is hoped to create a sea-thermal "garden" of phytoplankton and zooplankton, a microscopic plant and animal life that live at the base of the ocean's food chain. Shellfish, crabs, and other marine organisms higher up in the trophic chain

Part 3—Solar Power

The conjunction of several events—the space program, looming fossil-fuel depletion, degrading environment, and chronic power shortages—is slowly turning man's eyes toward the sun as the ultimate answer to our energy problems. Unlimited power via solar energy, gathered and focused earthward by satellites, may yet prove to be the greatest tangible benefit from the space program.

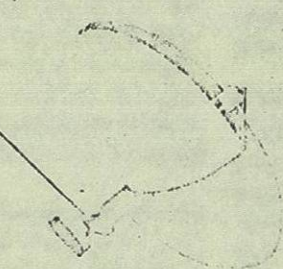
SAMUEL WALTERS¹

CAN THE sun be harnessed for large-scale electric power? The energy potential is unbounded. The thermal power intercepted by the earth's diametral plane is 1.7×10^{17} w, which is about a hundred thousand times larger than the world's present installed electric power capacity. It also has the virtue of remaining nearly constant over time periods of millions of years.

Why then has solar energy not been tapped for this

¹ Staff Editor, MECHANICAL ENGINEERING.

the cells, flows through a 2-in length to a solar cell. The energy is converted into d-c power by a diode. The satellite is exposed to the sun except for a 1.2-hr interval before and after equinox. Satellites, properly designed during the 1.2-hr interval, can maintain a continuous flow of power for an emergency storage system. An alternative plan is to use a non-equatorial orbit. The satellite power is stationary with respect to the sun to move in and down about with a 24-hr period, the equinox period. How feasible is this scheme? It has been discussed in various forums over the last few years. And recently the National Science Foundation devoted an entire workshop to the subject. The consensus is that the technology is not yet available for a solar power plant that has been realized. Success would be a gratifying belt of solar orbit "satellites" intercepting the solar power, or 1.34×10^{17} w, in the form of d-c power to widely distributed stations on the surface of the earth. Such a power plant would produce 1.17×10^{16} kw-hr of energy or over 200 times the energy produced by the world's power plants [1] (figures added).



purpose? Principally because it is intermittent and too diffuse when it reaches the earth. (Night, clouds, and dust reduce the "sun time" to a "use time" of about 20 percent of the full time.) To "collect" it, large amounts of real estate, including an elaborate storage system, would be required.²

Obviously, the flux of solar energy should be intercepted not behind the "dirty basement window" of the cloud-shrouded night-affected earth, but in a satellite orbit high above the earth's surface where "real estate" has no meaning. Such an audacious idea has been proposed by Peter Glaser, Mem. ASME, and head of engineering sciences at the Arthur D. Little Laboratories [1].³ A large space platform composed of a mosaic of solar cells hovers in synchronous orbit with the earth's rotation at a height of 22,300 mi (35,600 km). Solar energy, converted to electrical power by

² A solar-electric power plant of 1000-MW capacity, with a conversion factor from solar power to electrical power of 10 percent, would require a solar power input of 10,000 MW, or 10^{16} thermal w. According to Daniels [15] the average solar power at the earth's surface amounts to about 500 cal/cm²/day. This, when averaged over a full day, gives an average solar power input of about 2.4×10^{-3} w/cm². Then the area of the earth's surface required to collect 10^{16} w of solar power would be 10^{16} w / (2.4×10^{-3} w/cm²) = 42×10^{19} cm², which would be 42 km², or a square area of 6.5 km per side.

³ Numbers in brackets designate References at end of article.

System Outline

- Basic elements of a solar power plant would consist of:
 - Orbit characteristics to insure that the space platform is constantly exposed to solar radiation and that the radiating area can beam energy to any desired point.
 - Solar energy conversion devices of high efficiency (80 percent or better).
 - Transmitters capable of beaming the converted energy to an earth receiving station in a spectral region where minimum atmospheric absorption and scattering would be encountered.
 - Earth receiving stations capable of accepting the required power density and transmitting the energy to power-distribution networks.

Orbit Location

The system consists of two satellites in synchronous orbit (22,300 mi altitude in an orbit parallel to the earth's equatorial plane). The satellites are about 21 deg out of phase and about 7900 mi apart to insure that one satellite is always illuminated during the time the other is in the earth's shadow, an event that occurs at least 1 hr each day for 25 days preceding and following the equinoxes. At this height and phase difference both satellites have a direct line of sight to the same point on earth.

Conversion Devices

Silicon solar cells have been the primary source of power for the Ranger, Mariner, and Surveyor spacecraft and almost all other unmanned space missions. As a commercial power-conversion device, however, the cell's usefulness is circumscribed by low efficiency and high costs, 10 percent and \$4, respectively, for a cell 1 x 1 1/2 in. Large-scale use demands a price better than 4 cents and an efficiency raised to 80 percent or better. But here again, one can assume accelerated progress based on the needs of large spacecraft now being designed for missions in earth orbit and for exploration of the moon and planets.

Solar-cell arrays already have grown, in the space of a few years, from a few square feet to several thousand square feet in large lightweight deployable arrays with power levels in the tens of kilowatts. And underway are new approaches to increase cell efficiency and reduce cell cost: optical concentrators to focus solar radiation on an individual solar cell in order to reduce the number of cells required, multicellular devices, and new manufacturing processes such as the manufacture of solar cells from webbed dendrite silicon [4] or from extrusion of a ribbon of silicon single crystals.

But most promising of all is the discovery of organic-type compounds with semiconductor properties. This could open the way to a major advance in photovoltaic efficiency.

According to Glaser and others [1, 5, 6] the maximum theoretical efficiency of 24 percent inherent in the inorganic single-crystal semiconductor may not pertain to organic-type materials where charge creation and motion depend upon the long-range intramolecular charge transfer in heavy molecules found in biological systems (nerves, for example). Says Glaser: "The semiconducting properties of such molecular systems may be very different in character from those of in-

the cells, flows through a flexible superconducting cable 2 mi in length to a satellite station where, converted to microwave energy, it is transmitted earthward unimpeded by atmosphere and clouds. It is then reconverted into d-c power by an antenna-rectifier array. The satellite is exposed to full sunlight all the time, except for a 1.2-hr interval every 24 hr for 25 days before and after equinox. By using two or even more satellites, properly spaced, the interruption of power during the 1.2-hr orbital night can be avoided. A continuous flow of power is thus assured, obviating the need for an energy storage system on earth.

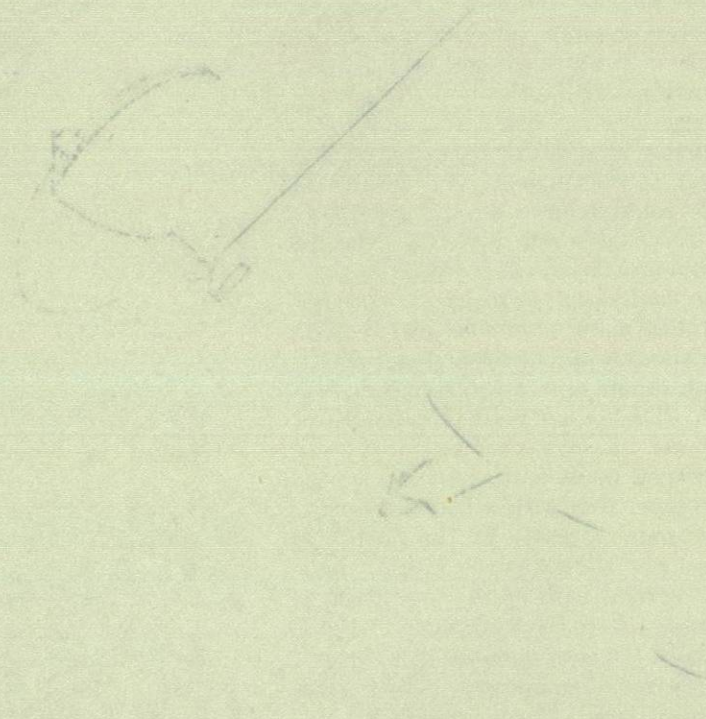
An alternative plan is to place a space power station in a non-equatorial orbit with a seasonal rhythm pattern. The satellite power station is now no longer stationary with respect to the earth's surface but appears to move up and down above the southern horizon with a 24-hr period, the swing being the greatest during the equinox period.

How feasible is this scheme? Technological details have been discussed in various journals during the past few years. And recently the *Journal of Microwave Power* devoted an entire issue to the subject.⁴ The consensus is that it is feasible, although in sheer engineering magnitude, such a system surpasses anything that has been realistically planned in the past.

Success would bring enormous rewards. An earth-girdling belt of solar cells 3 mi wide in synchronous orbit "would intercept 1.68×10^{15} watts of solar energy. At the present level of technology, eight percent of this power, or 1.34×10^{14} watts, could be provided in the form of d-c power to widely distributed locations over the surface of the earth. Such a power level would provide 1.17×10^{15} kw-hr of electrical energy per year, or over 200 times the requirements for the year 1980" [1] (italics added). In addition, the directed beams could be used to hasten the evaporation of the seas or lakes, to control rainfall in selected locations, to increase hydropower potentials, to heat frozen areas, and for other beneficial uses [2].

Many of the working elements of such a system are close at hand. The first part of the project—development of the components for power generation, conversion, and transmission, would be similar to projects accomplished in the space program during past years. The other phases of the project, such as manufacturing the cells and other components in great numbers, transportation into orbit, control of attitude, orbital altitude, and temperature, operation of electric systems, and remote control of the station, would not be new in kind, but they would be of a scale and magnitude entirely without precedent. (This includes the use of humans to deploy and maintain the solar energy collector and microwave antenna.) For example, one NASA official [3] estimates that, based on present technology, a solar plant providing one-tenth of the present United States power needs would have a total mass exceeding 200,000 tons. In the not-too-distant future, improvements in efficiencies and lightweight designs could bring about "a reduction of this total mass to 50,000 or 20,000 tons, possibly even lower." These latter figures are within sight of the capabilities of earth-to-orbit shuttle systems now on the drawing boards.

⁴ Dec. 1970 issue.



Part 3—Solar Power

The conjunction of several events—the space program, looming fossil-fuel depletion, degrading environment, and chronic power shortages—is slowly turning man's eyes toward the sun as the ultimate answer to our energy problems. Unlimited power via solar energy, gathered and focused earthward by satellites, may yet prove to be the greatest tangible benefit from the space program.

SAMUEL WALTERS

Can the sun be harnessed for large-scale electric power? The energy potential is stupendous. The thermal power intercepted by the earth's diameter is 1.7×10^{17} w, which is about a hundred times and times larger than the world's present installed electric power capacity. It also has the virtue of remaining nearly constant over time periods of millions of years.

Why then has solar energy not been tapped for this

purpose? Principally because it is intermittent and too diffuse when it reaches the earth. (Night, clouds, and dust reduce the "sun time" to a "use time" of about 20 percent of the full time. To "collect" it, large amounts of real estate, including an elaborate storage system, would be required.

Obviously, the flux of solar energy should be intercepted not behind the "dirty backyard window" of the cloud-shrouded night-affected earth, but in a satellite orbit high above the earth's surface where "real estate" has no meaning. Such an ambitious idea has been proposed by Peter Glaser, Alan A. G. and Fred of engineering sciences at the Arthur D. Little Laboratories [1]. A large space platform composed of a mosaic of solar cells hovers in synchronous orbit with the earth's rotation at a height of 22,300 mi (27,000 km). Solar energy converted to electrical power by a solar-electric power plant of 1000-MW capacity, with a conversion factor from solar power to electrical power of 10 percent, would require a solar power input of 10,000 MW, or 10¹⁰ federal w. According to Glaser [1], the average solar power in the earth's surface amounts to about 800 cal/cm²/day. This, when averaged over a full day, gives an average solar power input of about 2.4×10^{17} w/cm². Then the size of the earth's surface required to collect 10¹⁰ w of solar power would be $18'' \times 10^{17}$ w/cm² = 42×10^{10} cm², which would be 42 km², or a square area of 6.5 km per side.

*Numbers in brackets designate references at end of article.

organic semiconductors, and hence may have no efficiency limitation."

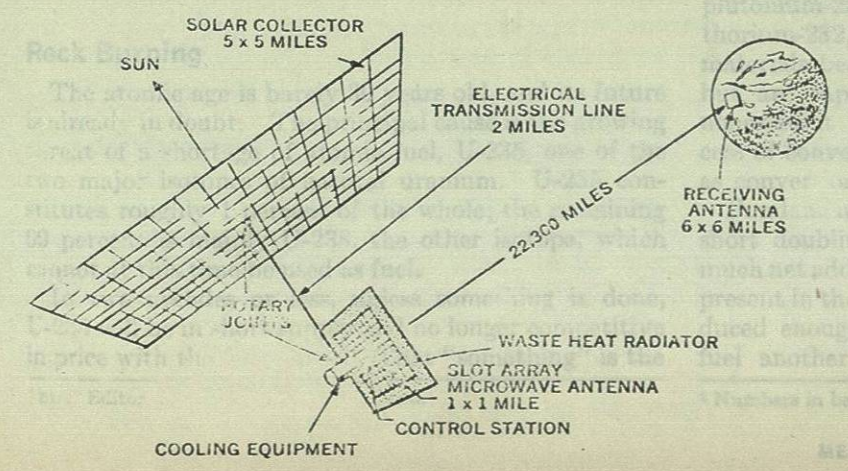
The "difference in character" is based on the fact that charge creation and motion in the inorganic single-crystal semiconductor are related to the primary act of light absorption, whereas in high-molecular-weight organic systems there is a distinction between charge formation in a molecule and diffusion through the bulk medium. This means the charge may be transferred within the molecule before motion in an adjacent molecule or vacancy site occurs. Advantage can thus be taken of both the low-energy gap of such materials and a possible low rate of thermal backward diffusion of charge. Theoretically therefore, organic systems promise higher efficiency than inorganic semiconductors; they would weigh less and could be produced in large quantities at a much lower unit cost.

Attainment of a conversion efficiency of 80 percent will radically alter the prospects for commercial solar power. A space platform with 8.7 sq mi of collector area (3.3 mi in diameter) would be all that would be required to meet the power needs of the entire northeastern section of the United States [1]. The weight of the collector would then be reduced to about 160 tons, exclusive of supporting structures. This is well within the cost capability of a space program employing reusable shuttles to assemble space structures. Such an earth-to-orbit shuttle with a payload of 20 tons is now on the drawing boards [3].

Power Generation and Transmission

The illustration below shows the main elements of a system designed to beam 10,000 MW earthward, enough power to supply the city of New York and its environs. Because of the inefficiency of present-day solar cells, the solar collector spreads over a 25-sq-mi area. Solar energy is here gathered, converted to d-c electric power, and transmitted to the microwave generators along a transmission line 2 mi long. The line is superconducting to reduce weight and power losses. Along its entire length, multiple-stage refrigerators maintain the proper temperature. The line is also articulated to provide relative movement between the solar collector, which must maintain its orientation toward the sun, and the microwave generators, whose radiating antennas are beamed to a receiving antenna on earth.

The microwave power transmission system consists of three major parts:



Courtesy of Arthur D. Little Inc.

Diagram of the main elements of a satellite solar power station designed to produce 10,000 MW, enough power to supply the city of New York and its environs.

System Outline

- Basic elements of a solar power plant would consist of:
 - Orbit characteristics to insure that the space platform is constantly exposed to solar radiation and that the radiating area can beam energy to any desired point.
 - Solar energy conversion devices of high efficiency (80 percent or better).
 - Transmitter capable of beaming the converted energy to an earth receiving station in a desired region where minimum atmospheric absorption and scattering would be encountered.
 - Earth receiving station capable of accepting the required power density and transmitting the energy to power-distribution network.

Orbit Location

The system consists of two satellites in synchronous orbit (22,300 mi altitude in an orbit parallel to the earth's equatorial plane). The satellites are about 21 deg out of phase and about 7000 mi apart to insure that one satellite is always illuminated during the time the other is in the earth's shadow, an event that occurs at least 1 hr each day for 25 days per year and following the equinoxes. At this height and phase difference, both satellites have a direct line of sight to the same point on earth.

Converter Devices

Recent solar cells have been the primary source of power for the Ranger, Mariner, and Surveyor space craft and almost all other unmanned space missions. As a commercial power-converter device, however, the cell's efficiency is unacceptably low (10 percent) and high cost (10 percent) and 24 percent, respectively, for a 1 x 1 ft cell. Large-scale use demands a price better than 4 cents and an efficiency nearer to 30 percent or better. But here again, one can require accelerated progress based on the needs of large spacecraft now being designed for missions in earth orbit and for exploration of the moon and planets.

Although solar energy already flows in the space of a few years, from a few square feet to several thousand square feet in large lightpipes or photovoltaic arrays with power levels in the tens of kilowatts. And numerous other approaches to increase cell efficiency and reduce cell cost—optical concentrators, heterojunctions, and anisotropic materials—all in one, to reduce the number of cells required, multi-junction cells, and new materials, have been used with some success in laboratory conditions. The most promising of these is the heterojunction of organic polymers with semiconductors.

According to theory, and other 1/2 of the main reason for the low efficiency of 10 percent inherent in the inorganic single-crystal semiconductor may be the problem to organic-type materials where charge creation and motion depend upon the intermolecular interaction. Charge transfer in heavy molecules found in biological systems (nucleic acids, for example, DNA, RNA) is a right of the capabilities of earth-to-orbit shuttle systems now on the drawing boards.

The cell flows through a flexible superconducting cable 2 mi in length to a satellite station where, converted to microwave energy, it is transmitted earthward unimpeded by atmosphere and clouds. It is this room-temperature d-c power to an antenna receiver array. The antenna is exposed to full sunlight at the time, except for a 1.2-hr interval every 24 hr for 25 days per year and after equinox. It uses the same solar energy path as the space platform, the installation of power during the 1.2-hr interval night can be avoided. A continuous flow of power in this sense is obtaining the need for an energy storage system on earth.

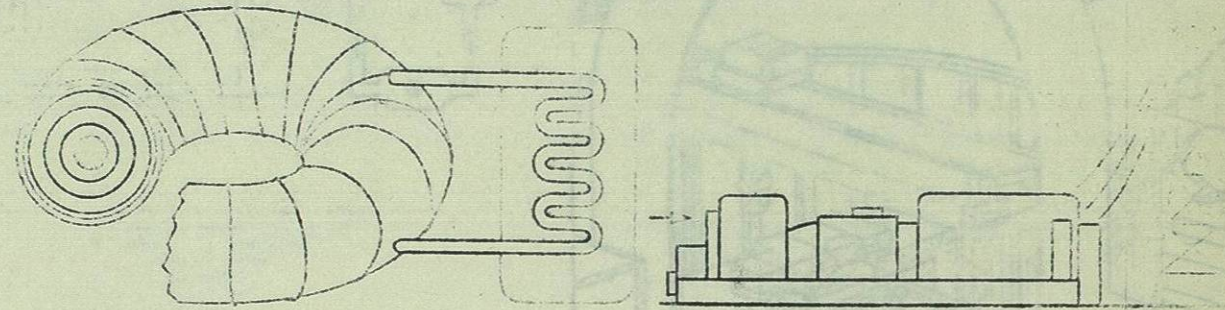
An alternative plan is to place a space power station in a non-equatorial orbit with a seasonal rhythm pattern. The satellite power station is now in orbit, stations with respect to the earth's surface but appear to move up and down above the southern horizon with a 24-hr period, the swing being the greatest during the equinox period.

How feasible is this scheme? Technological details have been discussed in various journals during the past few years. And recently the Journal of Spacecraft and Rockets devoted an entire issue to the subject. The consensus is that it is feasible, although in short-term hearing magnitude, such a system requires anything that has been technically planned to date.

Success would bring numerous rewards. An earth-girdling belt of solar cells 2 mi wide in synchronous orbit would intercept 1.6 x 10¹⁶ watts of solar energy. If the power is sent to earthward, right amount of the power or 1.4 x 10¹⁶ watts could be provided to the form of d-c power to which distributed locations over the surface of the earth. Such a power level would provide 1.17 x 10¹⁶ kw-hr of electrical energy per year, or over 300 times the requirements for the year (1970) [1] (figures adjusted). In addition, the direct beam could be used to harness the expansion of the sun in lakes to control rainfall in selected locations, to reduce hydroelectric potential to heat frozen areas, and to reduce droughts [2].

Of the various elements of such a system, the most critical part of the program—development of the components for power generation, conversion, and transmission—would be similar to projects accomplished in the space program during the past few years. The major part of the program, such as manufacturing the cells and other components in great numbers, transportation into orbit, control of electrical systems, and temperature regulation of electric systems, and remote control of the station, would not be new in kind, but they would be of a scale and magnitude of magnitude without precedent. This includes the use of automatic control and manual control systems, and the use of remote control systems. For example, one of the major problems in the development of a satellite solar power station would be the need for a total mass exceeding 100,000 tons. In the earth-to-orbit launch, however, it is in efficiency and lightness that organic materials could bring a revolution. The total mass of 10,000 to 20,000 tons, possibly even lower. These latter figures are within the right of the capabilities of earth-to-orbit shuttle systems now on the drawing boards.

POWER IN THE YEAR 2001



Part 4—Rock Burning and Sea Burning

Dispersed in the rocks of the earth are enormous quantities of "fertile" low-grade uranium and thorium ores. These will be converted to fissionable fuel in an experimental breeder reactor, a power plant that produces more nuclear fuel than it consumes. Success would assure a supply of low-cost energy for thousands of years. Our finite reserves of coal, oil, and gas would then be used as sources of organic molecules rather than as sources of heat. As for "sea burning," the process of extracting energy through fusion of the heavy isotopes of hydrogen, this is still a physicist's dream, but the lineaments of a practical device can be discerned in the emphasis on its scientific feasibility and some rudimentary thought on the technological, economic, and social aspects of commercial fusion power.

SAMUEL WALTERS¹

Rock Burning

The atomic age is barely 30 years old, and its future is already in doubt. The principal cause is the growing threat of a shortage of atomic fuel, U-235, one of the two major isotopes of natural uranium. U-235 constitutes roughly 1 percent of the whole; the remaining 99 percent is mainly U-238, the other isotope, which cannot at this time be used as fuel.

In two decades or less, unless something is done, U-235 will be in short supply and no longer competitive in price with the fossil fuels. That "something" is the

breeding reactor, so called because it produces more nuclear fuel than it consumes. The now-wasted U-238, along with low-grade thorium ores, would be converted through neutron bombardment into fissionable fuel from the dwindling supply of U-235.

At the present time, U-235 in the form of a 5-lb fuel rod is already worth about a third of its weight in solid gold. The refining process—separating U-235 from U-238—is an expensive operation because both have the same chemical characteristics. Huge \$800-million separation plants do the job. The end product is a slightly enriched uranium containing about 3 percent U-235. The utilities pay the price because the potential of a single fuel rod is the heat equivalent of 6000 tons of coal [1].²

Breeding Reaction

The breeding reaction goes as follows: Uranium-238 (or thorium-232) is subjected to neutron bombardment in a reactor whose initial supply of fuel is uranium-235. Uranium-238 absorbs a neutron and is converted to U-239. The latter, by two short-lived radioactive transformations, changes spontaneously, first to neptunium-239, and then to plutonium-239. Likewise, thorium-232 absorbs a neutron and is transformed into thorium-233. This, in turn, changes radioactively into protoactinium-233 and then into uranium-233 [2].

Because they are fissionable, U-233, U-235, and plutonium-239 are called fissile isotopes. U-238 and thorium-232, on the other hand, are known as fertile materials because they are not themselves fissionable, but are capable of being converted into previously nonexistent isotopes which are fissionable. The process of converting fertile into fissile materials is known as conversion.

Fundamental to a successful breeding program is a short doubling time (the time required to produce as much net additional fissionable material as was originally present in the reactor). The reactor thus will produce enough fissionable material to run another identical reactor. An efficient breeding

¹ Numbers in brackets designate References at end of article.

The "diffusion" mechanism, based on the fact that charge carriers and holes in the insulating crystal semiconductor are related to the primary net of light absorption, whereas in high-molecular-weight organic systems there is a distinction between charge formation in a molecule and diffusion through the bulk medium. This means the charge may be transferred within the molecule before motion in an adjacent molecule or vacancy site occurs. Absorption can take place in both the low-energy gap of such materials and a possible low rate of thermal backscattering of charge. Practically, therefore, organic systems are more efficient than inorganic semiconductors. They would weigh less and could be produced in large quantities at a much lower unit cost.

Attainment of a conversion efficiency of 20 percent will radically alter the prospects for commercial solar power. A space platform with 2.7 m of collector area (33 m in diameter) would be all that would be required to meet the power needs of the entire northwestern section of the United States [1]. The weight of the collector would then be reduced to about 100 tons, exclusive of supporting structure. This is well within the cost capability of a space program employing reusable shuttles to assemble space structures.

A solar collector with a 2.7-m-dia. collector would have an area-to-weight ratio of 20 tons per square meter. Such an array would reduce the ratio of the individual tubes to the point where their design would be consistent with a modest extension of existing tube technology.

Earth Receiving Station

The capture and conversion of the 10,000 MW of microwave power beamed earthward from space is by "retrom" (contraction for retrodirective antenna), a device that combines the functions of a receiving antenna and rectifier. It is a large disc-shaped receiving field several square miles in area made up of highly efficient solid-state rectifiers dispersed throughout the array and terminated in small antennas. The array, as a consequence, is relatively non-directional, which eliminates pointing problems and minimizes mechanical tolerances [3]. The converted 6-c-power is then fed into a distribution network through superconducting transmission lines. Such networks have already received considerable attention, and research is being performed on this method for electric power transmission in this country and abroad.

Although the power densities in the microwave beam (roughly 1 w/cm²) are an order of magnitude greater than the solar radiation received on earth, the danger of living beings that might enter the beam, they are not high enough to cause major electric-charge effects. Safety devices would have to be developed and regulations established to prevent entry of objects or living beings into the beam. The problem of safety

Copyright © 1971 by McGraw-Hill, Inc.

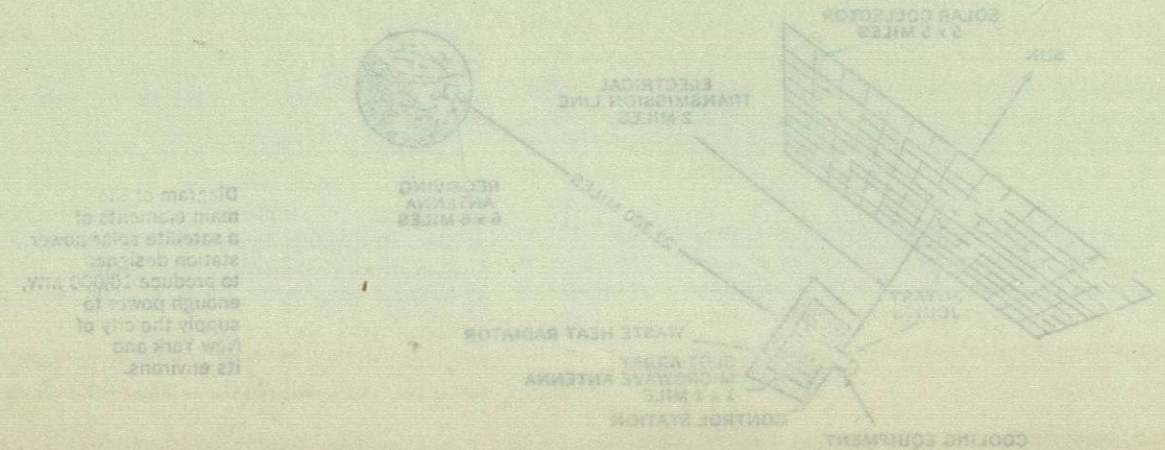


Diagram of solar power system showing the Sun, solar collector panels (2 x 2 miles), transmission line (2 miles), receiving station (6 x 6 miles), waste heat radiator, microwave antenna, control station, and cooling equipment.

ing and the manu- from pro- ap- that year recent

reduc- value, estic. action

and engineer- de- without solved,

with semiconductor and have that have an effi- ciency limitation.

The "diffusion" mechanism, based on the fact that charge carriers and holes in the insulating crystal semiconductor are related to the primary net of light absorption, whereas in high-molecular-weight organic systems there is a distinction between charge formation in a molecule and diffusion through the bulk medium. This means the charge may be transferred within the molecule before motion in an adjacent molecule or vacancy site occurs. Absorption can take place in both the low-energy gap of such materials and a possible low rate of thermal backscattering of charge. Practically, therefore, organic systems are more efficient than inorganic semiconductors. They would weigh less and could be produced in large quantities at a much lower unit cost.

Attainment of a conversion efficiency of 20 percent will radically alter the prospects for commercial solar power. A space platform with 2.7 m of collector area (33 m in diameter) would be all that would be required to meet the power needs of the entire northwestern section of the United States [1]. The weight of the collector would then be reduced to about 100 tons, exclusive of supporting structure. This is well within the cost capability of a space program employing reusable shuttles to assemble space structures.

Power Generation and Transmission

The illustration below shows the main elements of a system designed to beam 10,000 MW of microwave power to supply the city of New York under the assumption of the feasibility of present-day solar cells. Solar collector panels with a 2.7-m-dia. collector area are here gathered, converted to 6-c-power, and transmitted to the microwave receiver here a transmission line 2 mi long. The line superconductor is to reduce weight and power losses. A long distance light multiple-stage telescope maintains the proper aperture. The line is also intended to provide stability against the solar collector, which must maintain its orientation toward the sun and the microwave generator, whose reflecting antennas are beamed to a receiving antenna on earth.

The microwave power transmission system consists of three major parts:

² Editor, *MECHANICAL ENGINEERING*.