letters

Solar power from satellites—some questions

Peter Glaser's article "Solar power from satellites" in the February issue (page 30) advocates development of satellite-based solar collectors with microwave transmission to Earth. The question arises as to whether such an approach can compete economically with Earth-based solar-conversion systems. In figure 4 of his article, Glaser gives efficiency "goals" for each stage of the process. The overall efficiency is 6.8% for conversion of sunlight on the solar cells to electrical power at Earth's surface. It may be assumed for the purpose of approximation, that the collectors operate 24 hours each day in space.

By contrast, consider solar-energy systems on Earth's surface utilizing solar/thermal conversion techniques with heated fluids driving turbines. It is expected that such systems will eventually operate with 60% collector efficiency and 30% conversion of heat to electricity, for an overall efficiency of 18%. However, in many localities in the US, there are only about seven hours of collectible sunlight for only about half the days of the year. Thus the factor of 18% should be multiplied by $(7/24) \times (1/2)$ to yield the figure 2.6% for comparison with Glaser's system with 6.8% efficiency. These figures imply that the space system will be economically favored if the cost of the space system is less than 2.6 times the cost of a ground-based solar/thermal conversion system per unit area of collector. By "cost" we mean the entire cost in each case of all equipment and maintenance. The costs projected by Glaser are mostly wishful thinking. The cost of space transportation will have to drop by a factor of 50 from present costs; the weight-to-power ratio of cells will have to drop by a factor of more than 110, and the cost of solar cells per unit area will have to drop by a factor of roughly 50. Furthermore, Glaser's reason for choosing cells over heat engines, namely the requirement to radiate heat rejected by the heat engines, does not appear correct. There is a large heat-rejection problem with cells due to absorbed sunlight. That a space system could ever be merely 2.6 times as expensive as a ground-based system seems only remotely probable. Indeed, it is highly probable that any system ever designed for space could simply be placed on the ground and the

costs of energy storage and lowered efficiency would be much lower than the cost of transporting the system into space orbit and microwaving the energy back to Earth.

Like Gerard K. O'Neill (September 1974, page 32), who advocates "exploiting minerals mined from the moon, vegetable gardens and restaurants, ballet at one-tenth gravity—and a harvest of solar energy for Earth," Glaser is a dreamer. In rare cases, dreams can sometimes be converted to reality. But let us not confuse this "pie in the sky" with a serious proposal to supply low-cost energy to an energy-hungry world that has a moderate chance of success.

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3/4/77 *Richardson, Texas*

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In his article on solar power from satellites, Glaser states: "The third option, concentrating sunlight with mirrors placed in synchronous orbit to overcome the diurnal variation of solar energy on Earth, is equally unacceptable—in part because of the large area of mirrors that would be required in orbit for a reasonable concentration factor at a location on Earth, and in part because of the losses from absorption in clouds."

These are valid points, but there is a more basic limitation arising from the most fundamental properties of optical images. The diameter of the Sun's disk as seen from Earth is approximately 0.5 degrees, or about 0.01 radians. Any optical device producing an image of the Sun across a distance of 22 300 miles will inevitably have a diameter of about 0.01 times this distance, or about 220 miles at Earth's surface. This is *independent* of the size of the mirror in space (to first order), and in fact, is the *lower* limit. For the sunlight to be doubled (at noon) and be equal to noontime light at night, the mirror would have to be the same size as the image (and the author correctly notes that the mirror would have to be large).

There has been a lot of talk about space systems for solar-energy conversion in the last few years. I find it very difficult to believe that a practical, cost-effective large-scale space system will be built in our generation. The pages of PHYSICS TODAY have previously reported low-temperature schemes for the catalytic creation of free hydrogen in the presence of sunlight (at about 500°F as I recall), and current "low technology" can generate electricity via Freon pumps at moderate temperature differences (a few tens of degrees F and up). Surely such systems can be implemented more reliably and cheaply in shorter "technology tooling-up time" than any large-scale space system? It appears to me that a tough and thorough analysis should be undertaken for an effective comparison of the realistic feasibility and cost of the several basic solar-energy systems—including the concepts of using large areas of the arid West to supply hydrogen and/or electricity to the natural-gas pipelines and power-distribution grids using "ordinary" technology—before we rush off and spend billions on "high" technology approaches in space.

PAUL M. MULLER
3/3/77 *Ventura, Cal.*

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Peter Glaser's article was an interesting exercise in numerology, but I am afraid that it was not too much more than that.

He describes a space station that ingests sunlight and spits out microwaves

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which are received on Earth by a 10-km diameter antenna, to supply from 2000 to 15 000 MW. It is not clear to me if this is the level of energy in microwave form, or after conversion to 60-cycle alternating current. The difference in any case is about 25% according to Glaser, so it doesn't really matter much.

If I assume a 10-km diameter antenna as receiver, assume a solar constant of only one kW per square meter at ground level and a conversion efficiency that Glaser gives as 15%, my silicon cells at ground level would deliver about 12 000 MW dc. This is admittedly cut in half by the night phenomenon, but still, it seems to me that the difference in cost, the elimination of space stations and possible harmful effects from even low-level microwaves, settle the issue most definitely against the space concept.

HERBERT MALAMUD
3/3/77 *Westbury, N.Y.*

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Glaser has presented a potentially interesting system for power generation in the future, but I would like to mention one thought that was not covered in the article. I have been involved in nuclear-power development for a number of years and may be oversensitive to the overall safety aspects of a power-generation system, but it seems to me that the solar-power satellite has some potential as a weapon. The power-transmission system of such a satellite could be used by the government that built it during wartime, or could be used for blackmail by another government or by terrorists who gained control over the system. Such possibilities should not stop consideration of the solar-power satellite, but should be introduced into its evaluation from the start, rather than after 10 or 20 years of research and development.

JERRY F. KERRISK
3/3/77 *Santa Fe, New Mexico*

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Glaser may have neglected to deal with several points. What would be the effects of an accident that would leave the microwave beam coherent but pointed at the wrong spot on Earth (for example, midtown Manhattan)? Would not the very energy crisis that this satellite is supposed to solve raise the cost of rocket propellant to the point where the economies of using the large space shuttle would be cancelled out? Could not a cheaper system result by use of large arrays of solar cells on Earth?

This proposal looks like just one more aerospace industry boondoggle to me. It seems that the government takes the energy crisis so seriously that it is willing to support any idea, no matter how far-fetched, that might lead to a solution—except the one idea that is cheapest and most certain to succeed—namely, conservation.

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2/28/77 *St. John's, Newfoundland, Canada*

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I was most interested in Glaser's article, but saw that not much was said about possible effects of the proposed very large microwave power-density (20 mW/cm^2) on the Earth's ionosphere, although it is certain that it would produce extensive electron heating. If all electron–molecule collisions were elastic, the electron temperature would tend to rise within a few minutes (10 to 100 minutes, depending on altitude) to an incremental level

$$\Delta T \approx 1.2 \times 10^{16} \frac{\overline{m}F}{f^2} \mathrm{K}$$

above the ambient gas kinetic temperature. Here $\overline{m}$ is the average air molecular weight (16 to 30), F is the microwave power-density (2×10^5 erg/cm^2 sec) and f is the microwave frequency (2.45×10^9 Hz). At 300 km where $\overline{m} \approx 16$ we obtain ΔT = 6400 K, and at lower altitudes ΔT is larger. Inelastic processes (chemistry and molecular excitation) would probably become dominant before such a temperature could be reached.

Results from a large computer code show that an increase of 6400 K in electron temperature alone would not lead to large increases in ionization or pronounced modifications of ionospheric composition. It would probably produce extensive red airglow and extensive radiofrequency noise.

It is less clear what would happen in the stratosphere. Here there are fewer electrons, but the rate of electron heating by the microwaves would be very fast. The effects of hot electrons on atmospheric nitrogen oxides and ozone will have to be studied with some care.

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3/21/77 *Los Alamos, New Mexico*

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In his progress report on the imaginative proposal to obtain electric power from sunlight using satellites in geostationary orbit, Glaser has admitted the existence of some possible problems, such as oscillations of the structure, interference with communications, degradation of solar cells during transport through Van Allen belts, and difficulties in lifting space-fabricated structures from low to high Earth orbit.

Of more concern are topics not mentioned. In contrast to the satellite-based solar-electric converters, distributed terrestrial solar-cell systems would not increase the heat load of the Earth, would be relatively invulnerable to destruction by "killer satellites" launched by unfriendly nations, and would not result in the continuing loss of materials of ter-

restrial origin (such as 50 000 kg of argon per year per station for attitude control). Most significantly, dispersed land-based solar-electric converters would offer unique hope for the "two million villages" of the lesser-developed countries to maintain their individual characters, and yet enjoy improved living conditions resulting from the availability of modest amounts of electric power obtained locally, instead of from the enormous new power-distribution networks that the satellite scheme would require.

Let us hope that the glamour of this space venture does not divert all American funding and professional concern away from the development of economical geographically dispersed terrestrial solar-electric converters.

RICHARD M. WHITE
3/8/77 *Berkeley, California*

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As a physicist I have been aware for years of the satellite power concept, but I was surprised to hear Peter Glaser claim that satellite power is technically and economically superior to our other energy options. Direct conversion of solar radiation to electricity by silicon cells (the method used in the satellite system) is, with present technology, much more expensive than any other solar-energy conversion system; so how, I wondered, could satellite power be more feasible than terrestrial-based solar power?

After studying Glaser's article and its references, I find he makes satellite solar power look feasible by a combination of glib talk and misleading number juggling. The key point, on which hinges the whole project, is mentioned so casually that many readers may miss its deep meaning: Glaser assumes that spectacular improvements in silicon-cell technology are just around the corner—improvements that will dramatically reduce the cell's mass/power ratio. He says the best present technology "suggests" a ratio of 14 kg/kW (an optimistic number that he quotes without reference and that has never been demonstrated in practice), but then claims "projections based on improvements expected ... indicate 1.4 kg/kW *may* be achievable" (emphasis mine). This statement is so conditional, and the low mass/power ratio is so speculative, that his predictions are scientifically meaningless. Since about two thirds of the satellite's mass is in the solar collectors, and since the cost of putting mass into geostationary orbit is almost half the cost of the power station, satellite power becomes totally *unfeasible* if one uses a more conservative (and realistic) mass/power parameter.

By way of comparison, some other indirect solar-energy systems are feasible and economically competitive today, such as biomass conversion. Other systems, like solar thermal power generation (which uses relatively simple and well understood engineering technology) need only improve by factors of two to three to be cheaper than oil or nuclear-power systems. And similar modest (factor 2–3) improvements in the energy efficiency of our industrial technology would make it possible to fill all our energy needs for the next fifty years with our present power-generating capacity.

The satellite power concept is the brainchild of the military–industrial–aerospace complex. Misleading technical statements like Glaser's projections are commonplace whenever the military–aerospace corporations start lobbying for more gigabucks of public (our) money. These corporations and their associates in government consistently underestimate the costs of all their schemes. The new thing in the satellite power project is that "economic strength" has replaced "military strength" as justification for massive new government expenditures.

This brings up an important social issue at the heart of the energy debate. Our highly centralized energy system gives enormous economic power to a handful of energy corporations. These corporations tell us how much energy we "need" and how much we must pay them to supply it. If we try to solve our energy problem by introducing large amounts of new centralized technology, such as breeder reactors or energy satellites, we will quickly deepen our already heavy dependence on the energy suppliers and especially on the corporations controlling the new technology. The danger with the energy satellite scheme is that it threatens to make our entire economy *directly* dependent on the military–industrial–aerospace complex that will build it. In an era when the public is no longer willing to buy overpriced and unnecessary military hardware, an energy satellite system can give the military–aerospace corporations a new and perpetual reason to raid the Treasury. Is this the energy policy we want?

We have other energy options, ones that promote the decentralization of our energy system and our top-heavy economy. One of the exciting aspects of solar power is that because sunlight is free and available to everyone, we will not need the oil giants or the power companies if we use a variety of terrestrial solar-energy technologies. Economic decentralization will promote technical innovation, creative variety, and political independence. I want our energy policy to go in this direction. I see no reason why a few unproductive aerospace corporations should be allowed to own the Sun.

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3/22/77 *College Park, Maryland*

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We sincerely hope that at least some technique similar to Glaser's to tap ad-

ditional solar power will become a reality. Glaser's article, however, appears to ignore the important question of the environmental problem of electromagnetic-radiation pollution. Although the article briefly mentions that the method for transmitting the power from satellite to ground-antenna will be within the accepted "international limits" for electromagnetic-radiation intensity, it is not clear that the facts support that statement.

To what "international limits" is he referring? The recent articles by Paul Brodeur[1,2] that appeared in *The New Yorker* appear to indicate that no one agrees on a safe limit. The US standard[3] at 100 mW/cm^2 is a thousand times larger than that of the USSR,[4] which in itself is curious considering that the Russians have been doing research into non-thermal microwave damage much longer than has the US.

In particular, according to reference 9 of Glaser's article, the central beam intensity of the proposed design would be on the order of 90 mW/cm^2. This is far above the level he gives for ionospheric interactions to occur. Also, it is very close to what is considered by the US as the dangerous level for any exposure. Although Glaser indicates that further research needs to be done into these two problems, he goes on to say he *expects* the effects of both to be negligible. It is not clear how these intensity levels can have negligible effects.

Glaser goes on to state that radiation levels beyond 10 km from the center of the beam will be below the lowest "international standard." A simple calculation shows that not to be so in the best of circumstances. This leads to a question of why he states that economic reasons should dictate the final size of the receiving antenna rather than environmental and safety concerns?

The article also emphasizes the fact that the land underneath the ground antenna could support multiple land use. If we assume his stated 90% efficiency for the antenna, nowhere beneath it would the levels be lower than what the Russians consider a dangerous level, and at the center the amount of radiation would approach the upper limit of the US's acceptable limit. It would not appear to be the sort of land we would want to use.

Glaser further reasons that we could not reflect sunlight down to collectors on the earth because "serious ecological problems might arise from an interference with the diurnal cycle if this scheme were employed." It is interesting that he considers imbalances caused by photostimulation a "serious ecological problem," yet does not consider the same imbalances serious when they are caused by microwave irradiation.[5]

And finally, does mass production of extremely profitable items such as microwave devices necessarily make those products environmentally acceptable or safe for human use as he implies?

We would not like to be considered among those shrill environmentalists who favor no progress in necessary technology. But because there remain serious environmental questions regarding the biological effects of electromagnetic radiation in the microwave region, it appears to us that this proposed method of power transmission should contain a clearer statement of how the resultant problems will be avoided. Is the fact that this was not done just a further example of what Brodeur calls a "cover-up" of the problems of microwave radiation in the United States?

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3/21/77

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The idea of a solar-electric power station, usually of 10 000 MW size, continues to appear and capture some people's fancy and make others wonder whether space scientists and engineers have done all of their homework. In particular, Glaser has said "the energy required to produce the materials for power station construction and the propellants to place each satellite into orbit would be regenerated in about three years of operation." He should let us see the details of these calculations to learn, for example, if *everything* is included; "power station" might mean just the space part, not including the receiving station on Earth; "propellants" might mean fuel only, with zero credit for the rocket and its manufacture. Is amortization of the \$44 billion development cost, in energy, included? My point is simple: It takes energy to make energy. The fossil fuels currently available for investment are limited, as the US is past the peak of domestic production of both crude oil (peaked in 1970) and natural gas (peaked in 1972). Brian O'Leary's claim of construction, in space, of five such large power stations per year[1] would place, I believe, impossible demands on fossil-fuel investment. Let us see the largest deficit and the time delay until net

continued on page 66

energy is delivered. The schedules for Earth-bound nuclear plants, as by Price,[2] show that the allowable rate of growth (to obtain net energy output) is quite low if the net energy investment is large. It is hard to imagine that space-constructed plants would come out better.

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3/28/77

I feel that Glaser dismissed too lightly the potential health problem of a high-intensity microwave beam wandering over the surface of the Earth. He may be correct that a failure of the antenna-pointing circuits will cause the beam to become defocussed, but what about a failure in the attitude-sensing system? What about a collision with a meteor? One can imagine several failure mechanisms that would result in misdirecting a focussed beam.

The dangers of an uncontrolled beam are serious and need more attention than Glaser's otherwise excellent article implies they are receiving.

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4/18/77

THE AUTHOR REPLIES: **Donald Rapp** compares the efficiency of a solar-energy conversion system on Earth and in space. However, energy storage is required for a terrestrial solar-energy conversion system, based on thermal-electric or photovoltaic conversion. Therefore, to be competitive, terrestrial solar-energy conversion systems are being designed to supply peak power, possibly intermediate power, but not baseload power as is the case for satellite solar power.

As far as the cost projections for space transportation are concerned, the space shuttle was conceived for a level of space activity represented by the 1973 NASA payload model, or about one launch every two weeks. The heavy lift launch vehicle and orbital transfer vehicles from low-earth orbit to geosynchronous orbit, when designed for the payload delivery requirements represented by satellite solar-power stations, are projected to result in a fifty-fold reduction of transportation costs, based on detailed studies carried out by the aerospace companies working in conjunction with NASA/Johnson Space Flight Center (see figure 5 on page 36 of the February issue of PHYSICS TODAY). Reductions in weight-to-power ratio of solar cells are already occurring as a result of developments of thin-film solar cells based on the use of cadmium sulfide, gallium arsenide and amorphous silicon. The thrust of the National Photovoltaic Conversion Program is to reduce the cost of solar cells with the goal of reaching 50¢ per peak watt in 10 years. Indications are that the goals of this program could be approached with thin-film polycrystalline solar cells of acceptable efficiencies. Solar cells for use in satellites do not require active cooling systems and space radiators as is the case for heat engines that convert solar energy to electricity. Solar cells, even with modest concentration of sunlight, are designed to reach an equilibrium temperature by passive cooling means, utilizing appropriate coatings to radiate waste heat to space.

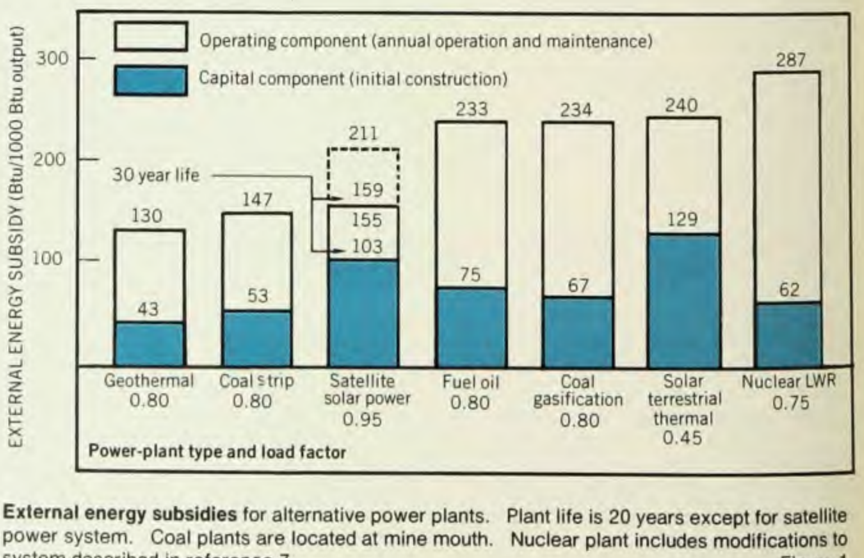
It may not be possible to meet the objective to supply low-cost energy to an energy-hungry world by solar-energy conversion methods, whether carried out on Earth or in space on a significant scale, when compared to the present low cost of conventional fuels.

I agree with **Paul Muller** that if appropriate catalysts to photodissociate water into hydrogen and oxygen could be developed with an acceptable efficiency and cost, they would provide a potential solution to meet long-term energy demands. Although the conversion of solar energy in chemical systems—whether to produce fuels directly, or to store solar energy in chemical form—is a promising area of research, practical applications of photochemical conversion are not yet within sight. Here, the requirements are for both "high science" and "high technology." It is very unlikely that anyone will rush off and spend billions on any approaches unless there is solid evidence that energy requirements can be met at reasonable costs.

The answer to **Herbert Malamud's** question is that the conversion of microwaves with dipole rectifiers results in high-voltage dc at the receiving antenna. If desired, high-voltage, long-distance dc transmission could be used, or dc could be converted to 60 Hz ac at the receiving-antenna site.

Depending on geographical location, solar cells on Earth receive about 1/4 to 1/10 the solar radiation of those in synchronous orbit, not only because of diurnal variations throughout the year, but also because of interruptions of solar radiation by adverse weather conditions, and absorption and scattering in the atmosphere. These terrestrial limitations to large-scale solar-energy conversion are among the reasons for considering satellite solar power. As far as the effects of microwaves are concerned, the satellite will be designed so that the microwave radiation beyond the receiving antenna site will meet agreed-upon international standards.

Jerry Kerrisk brings up the issue of the potential uses of satellite solar power for weapon systems. The microwave beam for power transmission from space to Earth precludes the use of the beam for hostile actions, because the low power density within the beam cannot be changed once the transmitting antenna diameter has been fixed and the microwave generators incorporated within it. Subversion of the peaceful function of the satellite by incorporating other design features (such as high-power lasers) can be avoided by making the satellite accessible to international inspection, or by arranging for international ownership, as is already the case with the INTELSAT communication satellites. Furthermore, the vulnerability of the satellite is the most effective deterrent to its use as a



External energy subsidies for alternative power plants. Plant life is 20 years except for satellite power system. Coal plants are located at mine mouth. Nuclear plant includes modifications to system described in reference 7.
Figure 1

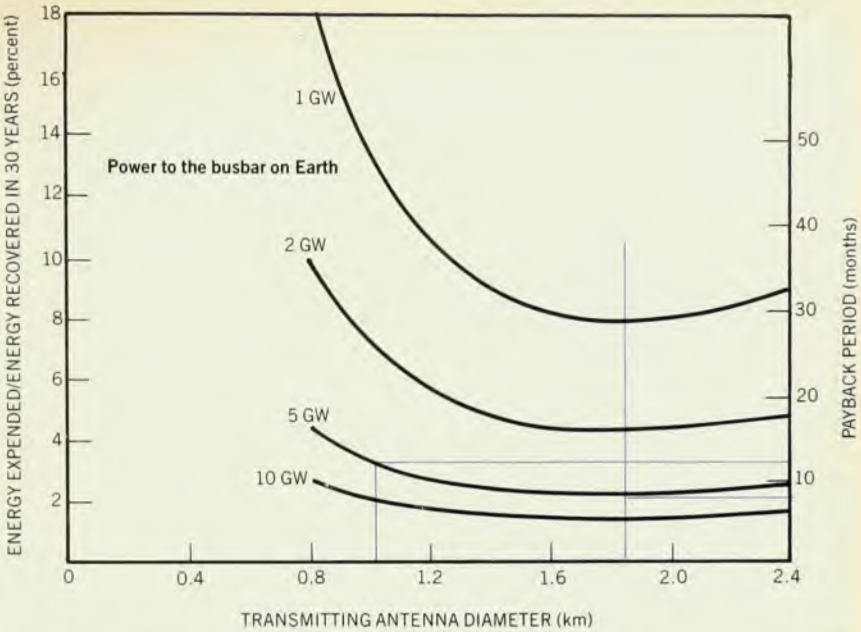
weapon system. Once the benefits of satellite solar power can be provided on a worldwide basis, it will be in the common interest of all nations not to interfere with the operation of satellite solar power systems.

Robert Yaes voices his concern of an accidental loss of control of microwave beam pointing. Even if failure of the beam phase-control system would occur, the beam would demodulate, and only communication signal levels of about 3×10^{-3} mW/cm^2 would be received on Earth.

The cost of propellant for the space transportation system, which is primarily hydrogen and oxygen, is a significant part of the space transportation system costs, as shown in the figure on page 36 of the article. The power produced by the satellite could be used to generate the required hydrogen and oxygen by electrolysis of water on Earth. About 18 months out of the planned 30 years of power delivered by the satellite would be required to generate the propellants required for placing the satellite into orbit. The total energy to produce all of the materials, including propellants, for the satellite will be regenerated in less than three years of satellite operation.

The benefits and costs of the satellite solar power development program, although not likely to be uniformly distributed, will benefit more than one sector of industry. The socio-economic impacts on energy self-sufficiency, on balance of payments, on trade balances, on employment of capital and labor resources, on regional economies, on materials allocation and energy requirements of the primary manufacturing and service industry sectors and on international policy will have to be assessed. By analogy, the positive results of the nation's space endeavors in areas such as communications technology, earth observations and computer science has been acknowledged by other nations as a major factor in achieving our societal goals. It is very likely that the successful implementation of the objectives of satellite solar power represents an opportunity to enter not only a new era of energy resource development, but, in a broader sense, the extension of human activities beyond the confines of Earth's surface.

John Zinn has identified the potential interactions of the microwave beam with the ionosphere as a possible effect leading to radiofrequency noise. Ionospheric interactions have been considered in the microwave power-transmission system studies by the Raytheon Company (see reference 6, February, page 38) and in the work on space-based solar-power conversion and delivery systems in conjunction with investigators interested in these particular phenomena (see reference 15). A number of experiments are being planned—using ground-based heating of the D and F layers with a simultaneous



Energy expended in placing one satellite solar power station into operation. Figure 2

transmission of a pilot beam from a small microwave transmitting array in synchronous orbit—to extend the existing data base pertaining to ionospheric effects along the lines Zinn has suggested.

The development of distributed solar electric converters is appropriately a high-priority objective in the near-term development of solar energy applications, as **Richard White** suggests. Satellite solar power is an option for the large-scale production of power to meet the future requirements of industrialized nations. Appropriate albedo control at the receiving antenna site to reflect solar radiation would control the heat addition to the Earth environment equivalent to the distributed terrestrial solar-cell system. The high efficiency of microwave-to-dc conversion would reduce thermal pollution at the receiving antenna site to levels that cannot be equaled by thermodynamic conversion methods.

The loss of material of terrestrial origin, such as argon, for station-keeping purposes, may be avoided by substituting lunar resources in later stages of satellite solar power implementation.

Satellite solar power is not claimed to be "superior to our other energy options," as **Tom Karr** asserts; but the studies cited in my article have found this option to be promising and worthy of serious consideration.

The mass-to-power ratio of 14 kg/kW was achieved with solar-cell arrays developed by Spectrolab, Inc, Sylmar, California. Present solar-cell arrays are about twice as heavy, to meet the requirements for automated deployment of the arrays and because 20-micron silicon solar cells are used.

Substantial improvements in solar energy conversion are projected to occur during the next ten years. Progress is being made in producing 50-micron single-crystal silicon solar cells,[1] and in the development of less-than-5 micron amorphous silicon solar cells.[2] Furthermore, thin-film photovoltaic materials, such as cadmium sulfide/zinc sulfide, gallium arsenide and zinc phosphide, are being developed under ERDA's photovoltaic conversion program,[3] in which about fifty academic, industrial and government laboratories are involved with a 1977 budget of about $70 million. The significant advances that have been made since the inception of the photovoltaic conversion program in 1975, and the solar-cell array designs being evolved as part of the satellite solar power development program, justify increasing confidence in projecting a tenfold reduction in mass-to-power ratios of solar cells beyond the present state of the art.

Continuing assessments of the benefits and costs of solar energy conversion methods, whether used on Earth or in space, and comparison with energy conversion methods based on alternative sources of energy will ensure that only the most appropriate technology to meet society's energy needs will be developed.

The international limits of microwave exposure, on which **Leslie Snively** and **John Drumheller** comment, still remain to be established. The microwave power density at the receiving antenna site is designed to meet the Eastern European standards. Several power density distributions of the form $(1 - r^2)^n$ with peaks of about 20 mW/cm^2 and with side lobes can be used. An ideal Gaussian distribution without side lobes has a peak of about 90 mW/cm^2, and is not the preferred distribution. The power density distributions that are being considered for the microwave transmitting antenna have a peak of about 20 mW/cm^2, so as to avoid potential ionospheric interactions. The power density in the side lobes will meet Eastern European standards at a distance of 10 kilometers from the beam center.

The receiving antenna provides a match between the specific dc load impedance and the incoming microwave beam. This match approaches 100%; reflection losses of less than 1% have been experimentally achieved. The 90% efficiency refers to microwave-to-dc conversion at the receiving antenna with 10% waste heat generated by the dipole rectifiers. Any small leakage of microwave radiation below the plane of the dipole rectifiers can be completely excluded from reaching the ground by installing a thin grounded copper-mesh screen.

The ecological effects of microwave radiation on the ionosphere, the atmosphere and the receiving antenna site are being considered, as indicated in references 4, 6 and 15 cited in my article. Mirrors located in synchronous orbit that reflect solar radiation to solar collectors on Earth would require an area at least 100 times the area of the solar collectors required for the satellite solar-power station. There would be a substantial increase in the absorption of solar radiation in the atmosphere during 24 hours a day, particularly for cloudy weather conditions, as compared to about 3% absorption of the microwave radiation in clouds. Furthermore, an area several orders of magnitude larger than the receiving antenna site would be illuminated as a result of both direct and scattered solar radiation. The effects of 24 hours of illumination on the terrestrial ecology, particularly when more than one reflecting orbiting mirror is used, are not yet known.

The fact that the microwave biological effects of satellite solar power were already discussed at a conference in 1972[4] indicates that these effects were identified as having potential environmental implications. Satellite solar-power development must include assessments of the environmental impacts to ensure that the planned operations will be environmentally acceptable.

In response to **Charles Birdsall's** enquiry about the energy payback calculations, let us look at the several energy payback calculations that have been performed. In reference 5 (below), the construction energy is considered a debit, as is the operational energy required to maintain the fuel cycle. Each plant's net operational energy is applied to paying back the debit energy. The operational energy needed to maintain the fuel supply was extended back to the construction process; however, for construction materials, the analysis included only the energy required at the primary material fabrication plant to convert ores into finished material stock. The results indicate that the energy required over the 30-year life of the satellite power station was 1.4 years for the LWR, 1.9 years for coal, 1.9 years for terrestrial solar thermal conversion and 1.4 years for the satellite solar power station.

In reference 6, the external energy subsidy was calculated by the methodologies developed for the Department of the Interior (see reference 7) with the results shown in figure 1. These energy subsidies correspond to a 3.25-year energy-payback time for a total satellite solar power station, including the operating subsidy. This figure compares with 2.7 years for the terrestrial solar/thermal conversion method shown (see reference 8).

In reference 9, the energy payback was calculated as a function of power delivered at the receiving antenna, with the results shown in figure 2. The energy-payback period of three years cited in my article was chosen as representative of a conservative analysis.

David Sloan recognizes that design approaches must be selected for the microwave-beam transmission system to fail "gracefully." The first approach, which ensures that the microwave beam is locked on to the receiving antenna, is based on the design of a retro-directive array. A reference beam transmitted from the center of the receiving antenna controls the phase front of the beam launched by the transmitting antenna. Failure of the attitude control system could prevent the reference beam from being received at the transmitting antenna with resulting loss of phase-front control. This would lead to demodulation of the beam, which, when received on Earth, would have a power density of 0.003 mW/cm^2. The second approach is to switch off the solar-energy conversion system with a command signal sent from a control station on Earth. If photovoltaic conversion is used, the power can be interrupted quickly because there is no energy storage in the system, as would be the case with solar-energy conversion based on thermodynamic principles. Furthermore, the potential exposure to microwaves would be limited to a few seconds, which is well below the 5 minutes of permissible exposure at the 20 mW/cm^2 power density occurring at the center of the microwave beam.

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5/2/77

Questions of gender

A recent edition of a popular dictionary contains the following entry:

"**Ms.** (m'iz) n. Used instead of Miss or Mrs. (as when the marital status of a woman is unknown or of no interest) [Ms. Mary Smith]"

As a logical extension of the spirit of the letter by Susan A. Gordon et al (February, page 13), and as a modest contribution to the enrichment of the English language, I would like to propose the adoption (and recommend the use) of the following noun:

"**Ps.** (p'iz) n. Used instead of Ms. or Mr. (as when the gender of a *person* is unknown or of no interest) [Ps. P. Potter]"

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If language reflects the attitudes of a society, then changes must first be made in attitudes in order to be reflected in the language, and not vice versa.

Carried to its logical limit, the move to remove all suffixes and prefixes indicative of gender will lead to such curiosities as "chairpeople" and "wopeople," as Alvin Radkowsky has suggested, perhaps a trifle facetiously. The movement to obtain equal opportunities and respect for women may wish to consider expending more of its energy in seeking out and encouraging capable women, than with its seeming preoccupation with changing words. No inequity is funny, but surely there should be some sense of proportion.

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