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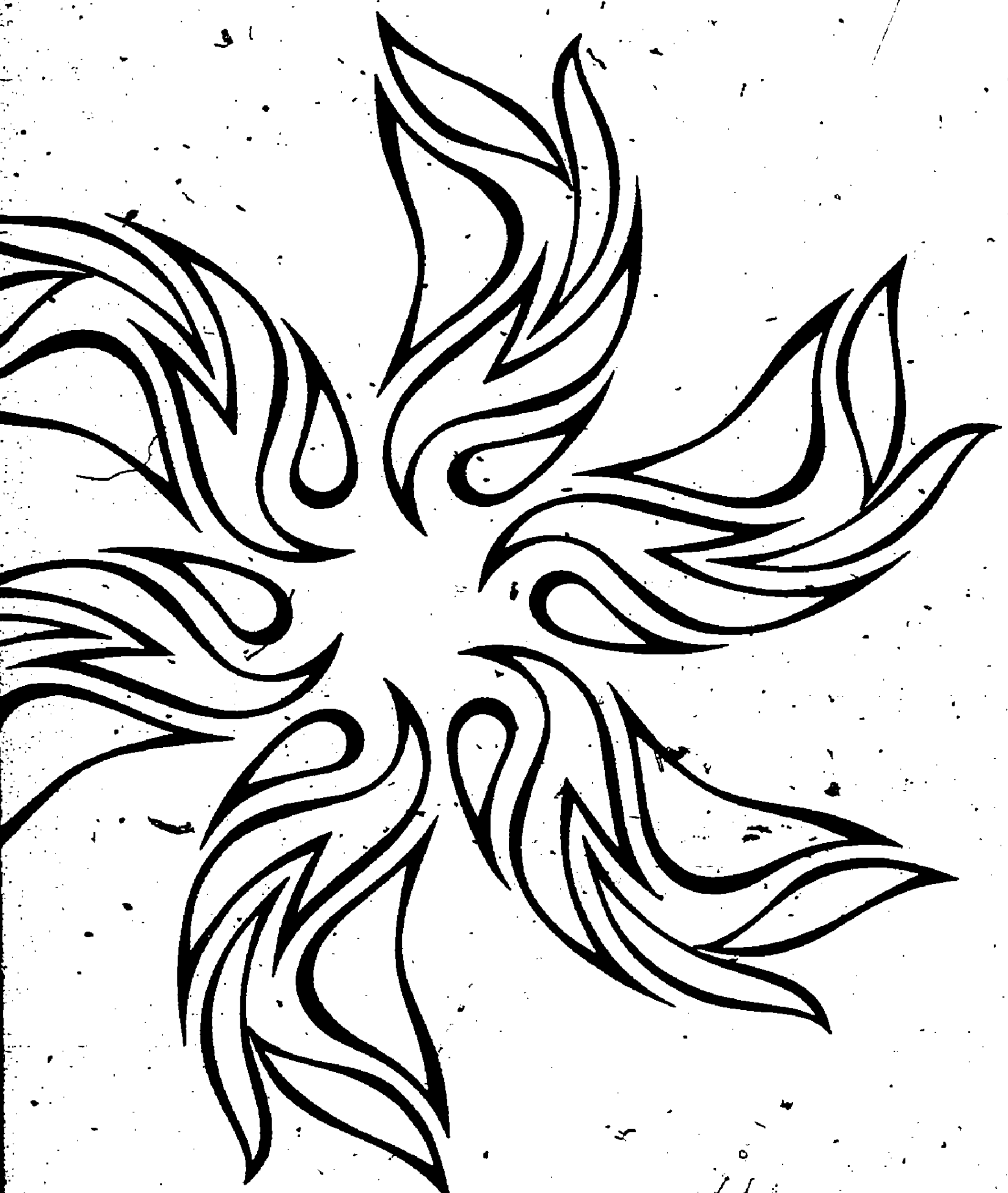
ABSTRACT

This report discusses many of the economic and policy questions related to the widespread introduction of solar power, presents recent progress in developing solar technologies and advancing their economic feasibility, and reviews some recommendations that have been made for achieving the early introduction and sustained application of solar technology, including suggestions for improving the federal solar energy program. Some of the topics included are: solar thermal energy, photovoltaic solar cells, biomass, wind energy conversion, small-scale hydropower, ocean thermal energy conversion, and energy storage. (BB)

SOLAR ENERGY

PROGRESS AND PROMISE



Council on Environmental Quality

April 1978

EXECUTIVE OFFICE OF THE PRESIDENT
COUNCIL ON ENVIRONMENTAL QUALITY
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Our energy dilemma is both real and complex. It can be characterized, however, by three simple but important observations.

- Today, oil and gas provide 75 percent of the energy that we consume. Yet domestic production of both has been declining for most of this decade, and excessive imports of these fuels are already hurting the United States economy.

- We in the United States have been extravagant in our use of energy. Our inefficient energy habits are costly both in terms of economic health and environmental quality. The case for doing better is clear: we can reduce the amount of energy required to meet our present needs by 20 to 40 percent through technical improvements; we can generate more jobs by investing in energy conservation than in energy supply.

- Despite the great potential of energy conservation, it alone will not be sufficient. We must also shift from oil and gas to other sources of supply. Yet, the two most readily available, coal and nuclear power, are constrained by environmental and social problems.

It should not be surprising then that many of us in government and elsewhere are returning again to the questions: What can we reasonably expect of solar energy? And how soon?

Having examined the issue, our conclusion is that the prospects for solar energy are brighter than most imagine. The view of solar energy as a rather exotic energy source of little practical significance from the standpoint of our large energy requirements is no longer justified, and never have been.

This report summarizes the recent technical and economic progress which has led to this more optimistic evaluation of solar technologies and reviews the recommendations that have been offered for speeding their widespread use in the United States and abroad. Although it is not comprehensive, this report should provide a point of departure for those interested in better understanding the important role that solar technologies could play in our energy future.

Based on our review, the Council on Environmental Quality has reached some tentative conclusions about what would be reasonable goals for the United States in this vital area. No one's crystal ball works very well in examining energy futures, but based on available information and recognizing the uncertainties, we view the following goals as optimistic but achievable if we commit the necessary resources to them:

- To make economically competitive over the remainder of the century a variety of solar technologies for the production of heat, electricity and biofuels.

- To meet, by the turn of the century, a significant portion of our energy needs with solar energy. Although the actual contribution of solar energy will depend on an enormous number of decisions by the public and private sectors, we believe that under conditions of accelerated development and with a serious effort to conserve energy, solar technology could meet a quarter of our energy needs by the year 2000.

- To move, in the period beyond the turn of the century, to a society based predominantly on solar energy. It is now possible to speak realistically of the United States becoming a solar society. A goal of providing significantly more than one-half our energy from solar sources by the year 2020 should be achievable if our commitment to that goal and to conservation is strong. This transition to primary reliance on solar energy will require reliance on a wide variety of solar approaches: heat from solar collectors and from passive designs for new structures; electricity from small dams, wind turbines, photovoltaic cells, and high-temperature collectors; and gaseous and liquid fuels from biomass.

The fact that it is now possible to discuss this solar future realistically may be the most exciting energy news of our generation. It is a future that deserves to be explored and pursued vigorously.

The U.S. solar effort could not hope to succeed without a continuation of the dedication and ingenuity that have characterized the efforts of private companies, groups, and individuals over the past few years. Because of these efforts, we can now say with assurance that solar energy, in its many forms and with its many advantages -- above all, its promise of true energy independence in an environmentally benign way -- is in fact our best hope.

CHARLES WARREN
Chairman

GUS SPETH
Member

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I. Solar Energy Prospects: An Overview

Even with substantial conservation efforts, world energy demand is expected to double in 20 to 30 years.[1] At roughly the same time, world production of oil and gas is anticipated to level off -- possibly beginning in the 1980's in the case of oil.[2]

Caught between these forceful and ominous trends, the United States and other countries must make far-reaching changes in their energy systems within a few decades. Because the lead times involved are long, these changes must begin now.

The principal alternative energy sources for the United States are coal, nuclear power, and solar (direct and indirect).[3] As recognized in the National Energy Plan, all of these options will be used in the years ahead,[4] but recent developments have increased concern with both coal and nuclear as longer-term supply options and have provided the basis for greater optimism regarding solar.[5] The considerations are such that many thoughtful persons now believe we should adopt national and international strategies aimed at shifting as rapidly as possible -- perhaps within a few decades -- to a society based predominantly on solar energy.[6]

Energy is derived from the sun in several forms -- direct sunlight, wind, falling water, plant material (biomass), and ocean temperature gradients. Solar energy in general has certain rather obvious, but very important, characteristics:

* It is abundant and renewable. Huge amounts of solar energy are potentially usable. Solar energy flows through the earth's natural system at a rate about 10,000 times greater than all energy from the world's

fossil- and nuclear-powered machines.[7] In principle, with an average collection efficiency of only 15 percent -- achievable with present technologies -- all of our current energy needs could be met by using roughly 1 percent of our land area.[8] As a perspective, approximately 17 percent of our land area is now used for crops. A recent study of California explored the outlook for total reliance in the state on solar and geothermal energy, along with a strong emphasis on conservation.[9] The study recognized some drawbacks, but concluded that, from the standpoint of resources and technology, it should be possible to operate an advanced society in California solely on "indigenous renewable resources" -- even with a population nearly twice the present size and an economy nearly four times as great.

* It is universally available and not as vulnerable to large-scale human intervention whether by strikes, embargoes, fuel price boosts, or anti-trust agreements.

* Its environmental impacts are minimal. With careful design and operation, solar energy technologies can be expected to have far fewer and far smaller detrimental effects than conventional sources providing equivalent amounts of energy.[10] Unlike coal, solar poses little risk to climate and creates little direct air pollution; unlike nuclear, it poses no radioactive hazards and no risk of nuclear weapons proliferation. The principal impacts of solar energy are on land use, and even in that respect it may compare favorably with alternative sources of energy when the entire cycle of the energy system is considered.

* Its effects on the economy and employment are highly beneficial. Widespread adoption of the various solar technologies would create an

enormous number of jobs of many types -- from welders to plumbers, from sheet-metal workers to electrical engineers, from architects to carpenters. Several studies, as well as some new preliminary data to be published shortly, indicate that capital investment in solar heating or wind power systems will generate between two and five times as many jobs as the same expenditure for central station electric powers plants.[11] Similar conclusions follow from a recent analysis of the employment implications of solar energy development in California.[12] The study estimated that widespread use of solar space- and water-heating systems to help meet the state's energy needs alone could generate more than 375,000 jobs per year during the coming decade, cutting California's unemployment rate nearly in half.

All these attributes of solar energy indicate that it has the potential to be a leading source of U.S. energy supply, not just a supplement. Indeed, from the standpoint of technology and resources, there appears to be no reason why solar energy cannot meet most of our needs, given adequate efforts to increase energy efficiency.

That leaves these critical questions to be answered. For the various forms of solar energy, how long will it take to reach full technological and economic feasibility? Will government, industry, and the public take the initiatives necessary to overcome the barriers to solar development and to capitalize fully on its potential? What share of national and international energy demand will solar technologies be able to meet?

It is important to keep in mind that long-range commitments, and long-range action, are needed. If solar energy is to provide a major recourse for the fast approaching time when oil and gas go into decline, an early and sustained commitment to its development is essential.

It is also important that comparisons between solar energy and other energy systems be made equitably. Many current economic comparisons are seriously inadequate and incomplete.[13] They do not, for example, cover an adequate range of costs and benefits -- or subsidies and externalities -- through the complete fuel cycle. For example, in comparing solar energy to coal and nuclear, a full and fair analysis should include such frequently ignored cost items as occupationally related deaths and injuries, environmental damage, the ecological and aesthetic impacts of transmission lines, security and accident risks, government assistance, insurance and tax subsidies, and so forth. One recent analysis concludes that present corporate income tax deductions and credits provide gas and electric utilities with a negative or zero income tax for new investment.[14] The overall cost to the nation of incentives used by the Federal Government to stimulate energy production in the last several decades has been well over $100 billion (1976 $).[15] Conventional energy systems, including fossil, nuclear and large-scale hydro, received essentially all of the funds.

What, then, is the prognosis for solar energy development? The evidence available today, and reviewed in the following sections of this report, indicates the following:

o Solar energy is already a serious option with numerous applications at or near commercial feasibility.[16] Most prominent in this regard are solar hot water heating, solar space heating and cooling, small scale hydropower, wind, and fuels from biomass. Nonetheless, significant barriers still exist to increased use of this resource. In some cases, they are institutional; in others, further research, development and industry growth are needed to bring costs down to competitive levels. In all cases, there are governmental actions which could substantially reduce the period required for the meaningful introduction of each solar technology.

o The past few years have seen remarkable progress in solar economics and technology, and rapid improvements are expected to continue. There are good grounds for believing that, with appropriate private and governmental support, solar energy can contribute in a major way in this century to meeting our needs for heat, liquid fuels and electricity. Though estimates of solar's potential growth are hazardous and must be viewed with caution, CEQ's conclusion -- reflected in the Table on page 6 -- is that from 20 to 30 quads (quadrillion or 10^{15} Btus) per year from solar sources appear possible by the year 2000 if we push ahead rapidly. For comparison, current U.S. energy consumption is about 76 quads/year, f[illegible] which come from solar sources. Our conclusion is that with a strong national commitment to accelerated solar development and use, it should be possible to derive a quarter of U.S. energy from solar by the year 2000, with the major growth occurring after 1985.

o For the period 2020 and beyond, it is now possible to speak hopefully, and unblushingly, of the United States becoming a solar society. A national goal of providing significantly more than half of our energy from solar sources by the year 2020 should be achievable if our commitment to that goal and to energy conservation is strong. As the Table on page 6 indicates, this transition to primary reliance on solar energy will require the creative and extensive application of the range of sophisticated solar technologies described in this report.

The following sections of this report discuss many of the economic and policy questions related to the widespread introduction of solar power.

CEQ ESTIMATES OF MAXIMUM SOLAR CONTRIBUTION TO U.S. ENERGY SUPPLY UNDER CONDITIONS OF ACCELERATED DEVELOPMENT

(Units: quads per year of displaced fuel)[a]

	1977	2000[b]	2020[b]
Heating and Cooling (Active and Passive)	Small	2-4	5-10
Thermal Electric	None	0-2	5-10
Intermediate Temperature Systems	None	2-5	5-15
Photovoltaic	Small	2-8	10-30
Biomass	1.3	3-5	5-10
Wind	Small	4-8	8-12
Hydropower	3	4-6	4-6
Ocean Thermal Energy Conversion	None	1-3	5-10

Total U.S. energy demand in 1977 was 76 quads. Estimated total U.S. energy demand is from 80 to 120 quads for the year 2000 and from 70 to 140 quads for the year 2020.

(a) A quad is a quadrillion or 10^{15} Btus. Electricity is converted to equivalent fuel that would have to be burned at a power plant to supply the same amount of power. The conversion rate used here is 10,000 Btu per kilowatt-hour.

(b) The estimates in these columns are not strictly additive. The various solar electric technologies will be competing with one another, and their actual total contributions will be less than the sum of their individual contributions.

Part II addresses the recent encouraging progress in developing solar technologies and advancing their economic feasibility. Part III reviews some recommendations that have been made for achieving the early introduction and sustained application of solar technology. These include suggestions for improving the federal solar energy program.

II. Progress in Solar Energy Development

Until recently, conventional wisdom insisted that solar technologies could be a major source of energy only in the very long term. This view now is questioned increasingly because of rapid advances in solar development. Recent advances include fresh scientific innovations as well as steady improvements in the technological and economic performance of existing devices.

There has been particular progress in solar hot-water and space heating. Optimism also has grown regarding other small-scale, on-site solar energy devices, such as those capable of providing both electrical energy and heat for a building or mechanical power for an irrigation pump.[17] Within the last year alone, there have been many other encouraging signs --less costly and more reliable windmills are being constructed; more efficient processes are being developed to convert organic materials to gaseous and liquid fuels; the number of solar-heated houses has increased dramatically; the cost of photovoltaic cells has dropped sharply; and the development of small, solar-actuated engines has progressed substantially.

Here is a short review of this progress and the status of the major solar alternatives.

A. Solar Thermal

The most straightforward way to tap the sun's energy is by collecting it in the form of heat. This can be done directly through a roof or windows, or with special collection equipment. Systems designed to provide hot water and space heating for buildings are the principal examples, though there are other important applications, such as in agricultural crop drying.

These are far from a new concept. In the 1940's, there were tens of thousands of solar heating systems in the country, chiefly in Florida. The advent of cheap natural gas made them obsolete. Because the temperatures required by such solar heating systems are relatively low, solar collectors for them can be comparatively simple.

Other uses of solar thermal energy -- for example, space cooling, electricity generation, and solar-actuated heat engines -- typically require much higher temperatures and more technologically complex collectors. We review below three categories of solar thermal systems. They are distinguished chiefly by the temperatures achieved.

Solar Heating and Cooling - Of all the possible applications of solar energy, water heating and building space heating are the most advanced and the most nearly economic.[18] Generally, the so-called "active" solar systems use flat trays called collectors which first trap the sun's heat. The front of each tray consists of a transparent material such as glass. Solar radiation passes through this material to a black metal surface at the back where it is absorbed. A fan or pump circulates a fluid -- usually water or air -- through the hot collectors removing the heat. The heat may be used immediately to warm the building or may be stored in rock, water, or some other substance for later use.

Solar collectors can also be used in combination with a heat pump. By using the collectors to raise the temperature of the outside source from which the heat pump derives its heat, the pump's efficiency can be substantially increased. This more efficient combination of collectors and pump can substantially reduce the need for supplementary heat.

Of major importance, too, are "passive" heating systems, which use highly energy-efficient architectural designs to minimize the need for conventional fuels or active solar system equipment. Such designs might include large windowed areas facing south to take in winter sunshine, with overhangs to keep out excessive heat in the summer. Other features of some passive systems are earth berms or reduced window surfaces facing other directions to cut down heat losses in cold weather, shutters, special ceiling tiles, and other building materials.

Passive systems, which store heat in walls or floors, are highly efficient thermally, and it is quite feasible to cut heating fuel needs in half or more.[19] A new experimental classroom building at the Massachusetts Institute of Technology, using only passive solar features, is expected to derive 85 percent of its heating needs from the sun.[20]

In addition, passive techniques typically add little to the cost of a house. They are reliable and consist of few, if any, moving parts. Unfortunately, they normally cannot be added to existing buildings, except at considerable cost.

Direct solar energy cooling systems work on a variety of principles. Technological feasibility of several designs has been demonstrated, but further development work is needed before the systems will be economically competitive.

A number of studies have concluded that on-site solar equipment can now produce hot water for domestic use at costs competitive with electric water heaters in most parts of the country.[21] Based on life-cycle economics, the Office of Technology Assessment also has estimated that by 1985, combined systems should be able to provide supplementary solar hot water and space heating for residential and commercial buildings at prices competitive with electrical heat.[22] OTA found further that solar systems supplying all hot water and heating needs for large buildings can be designed in the next three to five years, and that such systems could be competitive in several regions of the country.

Commercial development of solar space-heating and hot-water technology is progressing rapidly, in spite of currently marginal economics when compared with natural gas and fuel oil.[23] Solar systems are available from almost 200 firms and the production of collectors is increasing dramatically. In 1976, it was more than 150 percent above the previous year. An even larger increase was anticipated for 1977. The number of houses supplemented with solar energy has increased from roughly 30 in 1973 to somewhere in the thousands today.

A number of projections have been made of the possible contribution that solar heating could make to meeting our energy needs [24] The Stanford Research Institute suggests that by the year 2000, solar heating and hot-water technology could lead to fuel savings of some 9 quads per year in the residential and commercial sectors. This is equivalent in energy content to about 4.4 million barrels of oil per day or about half of current imports. The report of a solar energy panel sponsored jointly by the National Science Foundation and the National Aeronautics and Space Administration estimates a potential contribution of between 2 and 8 quads by the turn of the century and between 10 and 23 quads by 2020. CEQ estimates energy savings of between 2 and 4 quads by 2000, and between 5 and 10 by 2020 (see Table, p 6.).

Since solar heating technologies are reasonably well understood, the emphasis of the Department of Energy (DOE) for active systems is on demonstration grants and market development activities designed to stimulate a large-scale manufacturing and installation capability. The DOE is also preparing a program plan designed to give a boost to the development and use of passive solar systems.[25] The program is expected to include a "passive initiative" which would involve the demonstration of a large number of passive solar designs in residential dwellings.[26] Other efforts include disseminating information and developing standards for equipment.

High Temperature Applications -- Solar thermal energy also can be used to produce high temperature steam to generate electricity. Several systems are under development, but most of the research effort has gone into what is known as the "power tower."[27] Under current designs, thousands of large, steerable mirrors (called heliostats) will be arrayed over an area of several square kilometers. The mirrors will track the sun and focus its light intensively on a central boiler, mounted on a tower several hundred meters above the ground.

The absorbed energy can be used to generate steam for a conventional utility turbine or for industrial processing. Projected sizes of feasible systems range from 100-kilowatt electric (KWe) to 100-megawatt electric (MWe), depending on tower height and the heliostat field layout.

System design studies nearing completion have found no major technical problems with this approach, and cost estimates indicate that with mass production, power tower economics should be comparable to those of other emerging solar technologies.[28]

The power tower is being developed in a number of stages beginning with a 5-megawatt thermal test facility due to be completed in 1978.

The Department of Energy also plans to begin construction soon of a 10-MWe pilot plant. This is to be followed by a demonstration plant in the mid-1980's with the most efficient size yet to be determined.

One concept under active consideration is to design the solar tower boiler so it will fit as a replacement for boilers in existing, conventional oil- or gas-fired electric power plants. Such "repowering" of present plants could permit great cost savings for utilities through continued use of their investments in buildings, turbines, and other equipment.

The potential capacity that solar thermal electric plants could displace has been estimated at 40,000 MWe by the turn of the century, contributing about 1.4 quads of energy Eventually, it is estimated, they could meet 20-30% of the Nation's electricity needs.[29] CEQ estimates solar thermal plants could contribute 0 to 2 quads by 2000 and perhaps 5-10 quads by 2020 (see Table p.6).

Intermediate-Temperature Systems - Most federal funding has gone either to low-temperature systems for solar heating and cooling or to high-temperature systems for steam generation as in the power tower.[30] Another area with great potential between now and the year 2000 is the intermediate-temperature system for industrial steam, heat engines, and community-scale energy needs.

Several types of solar collectors, using tracking mirrors less sophisticated than those of the power tower, are now being made in the U.S.[31] These systems can convert sunlight to heat in a temperature range higher than the 212°F limit of un-pressurized flat plate collectors but less than the roughly 900°F achievable with tower-type heliostats.

The potential market for intermediate systems is very large. It includes process heat for many industries such as chemicals, textiles, and food processing. About one-third of this industrial heat is used at temperatures below 600°F, and a recent federal study estimated that by 2000, solar technology could be used to replace about 7.5 quads of fossil fuel now used for this purpose.[32] This is equivalent in energy content to about 3.5 million barrels of oil per day. CEQ estimates the contribution of intermediate-temperature systems at 2-5 quads by the year 2000, and 5-15 quads by 2020 (see Table, p.6).

Another promising intermediate-temperature application is the small, solar-powered heat engine. This type of engine can be used to operate electrical generators, compressors for air conditioners, and water pumps. While American designs for such engines have been characterized as "archaic," European firms have developed fairly advanced systems.[33] Interest is increasing in this country and a number of U.S. firms now produce and sell prototype engines.[34]

One major use for solar engines could be to power irrigation pumps. More than 300,000 irrigation pumps are employed in the western United States -- at an energy cost of over $700 million per year. Operation of the nation's first recent solar heat-engine irrigation facility began in 1977.[35] Although the 38-KW system, based on focusing collectors, is not currently competitive, substantial cost reductions appear possible. The price of the heat engine for the irrigation project was $50,000, but the Battelle Memorial Institute estimates that with mass production, this could be lowered to $3,000 or less.[36]

If 10,000 to 20,000 small heat engines were manufactured each year, it is estimated that the cost could drop to $200 to $300 per peak KW.[37] The Jet Propulsion Laboratory believes that units produced on the scale used in the auto industry could cost about $40 per KWe.[38]

Perhaps the most promising future belongs to integrated or "total energy" systems, in which intermediate-temperature technologies are used to produce electricity and heat on a factory or community scale.[39] The Department of Energy already has approved a Shenandoah, Georgia, project which by 1981 is expected to produce electricity, process steam, heating, and cooling for a textile factory employing 150 people. Community-scale solar thermal electric systems, by using waste heat for industrial steam or for residential and commercial heating and cooling, could combine the benefits of decentralization with greater freedom in siting housing units.

Also, a recent program started by the Department of Energy at the Jet Propulsion Lab is investigating the use of high-performance solar reflectors coupled with small heat engines to provide electricity for small communities.[40] Power output would be in the 1- to 50- MWe range. If they become commercially attractive, these systems could also provide high-temperature (up to 1800°F) industrial heat. There is promise that such smaller, modular systems might even be competitive with large, central power plants. DOE's Sandia Laboratory is now testing systems which could provide solar energy on a community scale for everything from electricity and industrial process heat to hot water for residential use.[41] A 1-MWe, small-community power plant is scheduled for start-up in about 5 years somewhere in the Southwest.

B. Photovoltaic Solar Cells

Photovoltaic cells simply but remarkably convert sunlight directly into electricity. Most of the cells manufactured today are thin wafers, containing semiconducting materials, that produce a tiny current of electricity when the sunlight strikes them. With many cells arrayed together, significant amounts of electricity can be generated.

It is possible to fabricate many different types of solar cells.[42] The most widely used variety is made from silicon, one of the earth's most abundant elements. Solar cells have many advantages. They are plagued by no tricky maintenance problems and no direct pollution. They have great reliability and durability.

Another significant feature is that few economies of scale are realized by increasing the size of photovoltaic cell arrays. Thus the arrays are well-suited for small-scale, decentralized uses. This can obviate the need for transmission and other investments, and can facilitate combinations with other technologies.

The technical feasibility of utilizing photovoltaic cells is well established. Since the 1950's, they have powered space satellites and provided electricity to remote locations. The major obstacle to their widespread use has been their high cost. If cell arrays are to be generally competitive as a source of electric power, unit prices must drop roughly 90 percent. Even further economies will be needed before central power stations are economically feasible.[43] Substantial cost reductions already have been achieved, however, and there appear to be no fundamental barriers to further progress. Just a few years ago, solar cells manufactured for use in space cost 50 times more than those now being produced for terrestrial applications.[44]

Silicon solar cells having a peak sunlight-to-electricity conversion efficiency of about 13 percent are now commercially available at a price of $12 per peak watt.* However, prices are still dropping rapidly. Reductions to about $1 to $2 per peak watt are possible as early as 1980.[45] By the mid-1980's, a cost of $0.50 per peak watt appears possible, either through continued progress with silicon cells or through rapid advances in competing photovoltaic technologies. At this cost, on-site photovoltaic power should be competitive for many applications.

Photovoltaic systems which use mirrors or lenses to concentrate a large area of sunlight onto solar cells are also receiving increasing attention due to their cost-cutting potential. Cells designed for a 100-fold increase in light energy intensity do not cost appreciably more than conventional cells, but generate 100 times more power. Indeed, the cost of the sunlight concentrators rapidly becomes the dominating factor. The successful bid for the largest photovoltaic facility yet planned came in at less than half the price for non-concentrating silicon cells. Photovoltaic arrays using concentrators will be provided at $4.75 to $5.75 per peak watt, with deliveries starting May 1978.[46]

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* The costs and power output of solar cells are frequently cited in terms of "peak watt" which represents the maximum output of the cell achieved under the bright sunlight conditions that prevail around noontime. The average power from solar cells over the period of a day is of course less than the peak value.

Concentrating systems offer the additional possibility of supplying heat as well as electricity. In such "total energy systems," sunlight not converted into electricity can be collected from the cells and used to help meet a building's hot water and space heating needs.

New materials, such as gallium arsenide, for solar cells are also being being investigated and their conversion efficiencies may be as high as 30 to 50 percent compared with the 13 percent for silicon cells. Able to tolerate higher temperatures than silicon, these materials include both multiple-junction cells and a thermophotovoltaic cell being developed at Stanford.[47]

The use of thin-film technology offers another promising approach to photovoltaic cells. In principle, large areas of extremely thin layers of photovoltaic material could be inexpensively formed by chemical deposition or spray techniques. Developments along these lines could lead to dramatic savings in both material and manufacturing costs. While the efficiency of the only commercially available cells of this type is less than 5 percent, experimental cells have shown laboratory efficiencies greater than 10 percent.[48]

The range of technical options under investigation, coupled with the documented trend of sharply decreasing prices, provides a strong argument that photovoltaic technology can be made economically competitive in the foreseeable future, perhaps within a decade.[49] The Department of Energy is developing a new program for photovoltaic cell R&D. A February 1978 plan set a target date of 1986 for attaining the goal of a competitive price for photovoltaics of $0.50 per peak watt (in 1975 dollars) and an annual production rate of 500 peak MWe.[50] By 1990, DOE hopes to achieve a price reduction to within a range of $0.10 to $0.30 per peak watt (1975 dollars), which would lead to electricity costs of $0.04 to $0.06 per kilowatt-hour. Since current electricity costs are in the range of $0.03-$0.06, this should make photovoltaic systems economically competitive with other energy sources for central power generation as well as for dispersed, on-site applications.

If the DOE price and production goals are realized, installed capacity by the turn of the century could reach 75,000 peak MWe. This would lead to a fuel savings in the year 2000 on the order of a quad. CEQ's estimate for the photovoltaic contribution is between 2 and 8 quads by 2000, and by 2020, 10 to 30 quads (see Table p.6).

C. Biomass

Next to hydropower, biomass is the largest source of commercial solar energy in use in the United States. About 1.3 quads per year, or about 1.7 percent of the Nation's energy, is now supplied by biofuels.[51] Today's economically competitive uses include electric power generation using sugarcane residues in Hawaii and wood residues in Oregon, process steam generation from wood and pulp residues at paper mills scattered across the country, and the direct combustion of fuel wood to provide space heat for homes.[52]

Biofuels are fuels derived directly or indirectly from non-fossil plant material. They can be solid (e.g., wood or crop wastes), liquid (e.g., alcohols), or gaseous (e.g., methane or synthesis gas). Biofuels can be produced either from organic wastes, such as municipal and agricultural wastes, or from fuel crops -- plants grown specifically to produce energy.

Fuel crops are potentially the largest source of biofuels, but energy is not as valuable a crop as food or fibers and cannot compete for prime land.[53] The development of "energy plantations" to generate electricity by burning trees or some other energy crop on a sustainable basis has nonetheless received serious consideration.[54] The cultivation of marine or freshwater biomass offers another possibility. With marine biomass, for example, kelp plants would be attached to subsurface cable networks to form moored or floating rafts.[55] Adaptive biomass system that can make multiple outputs available (e.g., food, chemicals, fuels, fibers) in response to demand changes should be able to reduce the ultimate cost of energy delivered to the consumer.[56]

The terrestrial biomass resource is quite large.*[57] On a worldwide basis, net forest productivity exceeds annual consumption of fossil fuels, though comparatively little is actually used for fuel. Total annual world biomass production exceeds the present global energy demands by more than a factor of 10. In the United States, annual biomass production for food, lumber, paper, and fiber is estimated to be about 25 percent of our current energy demand, a surprisingly large figure.[58] Much of this material, however, must be regarded as a premium resource that is rather limited for fuel applications.

The biomass resource could increase dramatically with the development of plants with more efficient mechanisms for converting sunlight

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* Although the energy potential for marine biomass is enormous, many environmental and ocean-engineering questions remain to be answered before its potential can be fully assessed.

into biomass.[59] The resource could also be extended through improved conversion techniques. For example, if direct solar energy were used to help provide heat needed for thermochemical conversion, the efficiency of the overall process could be greatly increased.[60]

It would be difficult to overstate the importance of the biomass option. At present there are very limited technological alternatives to fossil fuel-based liquid fuels for ground transportation. In the absence of major breakthroughs in the development of batteries or inorganic liquid fuels, biomass offers the most practicable solar-based alternative for powering trucks, buses, and automobiles.

A number of estimates are available of the potential contribution that biomass could make to meeting our energy needs.[61] The solar Resources Group of the Committee on Nuclear and Alternative Energy Systems (CONAES) calculates that 8.0 quads of biomass could be annually available by 2000, and 9.9 quads by 2010. The Stanford Research Institute estimates that under optimistic conditions 5.0 quads could be used by 2000 and 11.0 quads by 2020. CEQ considers a maximum terrestrial biomass contribution of 3 to 5 quads per year achievable by 2000 (see Table p. 6).

The present DOE biomass program involves research in a number of areas. Research and development activities include work on anaerobic digestion, the production of alcohol by fermentation, thermochemical conversion of wood to oil, and lowering the costs of the production and collection of biomass. New developments are occurring at an accelerating rate.[62]

D. Wind Energy Conversion

A resurgence of interest is occurring in wind energy, an already well-developed technology.[63] Both private and public funds are being invested to improve windmills, which in the near future promise to generate electricity at costs comparable to those of conventional power plants. Both small (kilowatt-sized) and large (megawatt-sized) machines have the potential for marked cost reductions through mass production.

The rate at which wind energy can be introduced into the economy depends heavily on the results of current R&D programs and on subsequent commercialization efforts. The wind potential of the nation, excluding offshore regions, has been estimated to lie between 1 and 2 trillion kilowatt-hours (KWh) per year.[64] By comparison, total U.S. consumption of electricity in 1976 was about 2 trillion KWh. Several studies have concluded that, under conditions of rapid implementation, an electrical output of between 0.5 and 1.0 trillion KWh could be achieved by the turn of the century.[65] This is equivalent to a savings of 5 to 10 quads of fuel. CEQ estimates a possible contribution of 4 to 8 quads by 2000 (0.4 to 0.8 trillion KWh) and 8 to 12 quads by 2020 (0.8 to 1.2 trillion KWh). (see Table p.6)

A number of small machines for producing electricity already are on the market. Machines sized at 2 and 3 KWe are being sold as reconditioned units for $1,000 to $1,800 per KWe.[66] Somewhat larger machines (15 to 30 KWe) are becoming available at comparable unit costs. As a substantial market develops, the mass production of small-scale windmills should lead to significantly lower costs.

Large windmills are being developed by both the Department of Energy and private industry.[67] A 100-KWe machine has been undergoing tests for more than a year near Sandusky, Ohio. In January 1978, a 200-KWe wind turbine began generating electric power for Clayton, New Mexico. During 1978, two similar machines will be constructed, one in Puerto Rico and the other on Block Island, Rhode Island. The objective of the next phase in the largewindmill program is the construction of a 2-MWe windmill with a rotor 200 feet in diameter. The largest of the series, with a rotor 300 feet in diameter, is scheduled to be built in late 1979 at a cost of $10 million. Private companies are also installing large turbines, reportedly at costs lower than those of government-sponsored machines.[68]

DOE is studying windmill designs, different from the horizontal-axis type, which may have technical and economic advantages.[69] One concept being developed is the vertical-axis wind turbine. A 55-foot diameter Darrieus rotor, with blades shaped like an eggbeater, began operation in mid-1977. In a 22-mph wind, this machine produces 30 kilowatts of electrical power. During fiscal 78, studies will examine how the design might be improved to reduce costs and permit mass production.

DOE has also begun testing six commercially available, small windmills, with contracts being issued for the development of 40-, 8-, and 1-KWe machines. A proposal also has been made by the Bureau of Reclamation which involves the demonstation of a significant number of wind energy systems integrated into federal hydroelectric systems.[70]

A recent report prepared for DOE recommends a substantially expanded program to speed the widespread use of wind energy.[71]

E. Small-Scale Hydropower

Generating electricity from small dams is by no means a new idea, of course. But like some other outmoded or stagnant technologies, this option now is attracting renewed interest because of the high price of oil and other fuels.[72]

A recent report estimates that more than 14,000 megawatts electric of untapped hydropower potential exists at small sites -- 3- to 5-MWe -- across the United States.[73] At some of these sites, dams already exist; all that is needed is installation of electric generating facilities. In New England, for example, 112 hydro sites have been abandoned since 1941 because other sources of power became more economic. Many have now regained economic viability.[74] In addition to the potential of these small sites, an estimated 14,000 MWe is available in unfilled generation bays at existing dam sites of more than 5 MWe.[75] Projections of capital costs to utilize these sites range from $300 to $1200 per installed kilowatt, depending on the location and on whether dams and other facilities are already in place.[76] The maximum additional capacity potentially available by upgrading and expanding existing hydropower dams and by adding hydropower facilities to all existing large and small dams is estimated to be 54,600 MWe.[77] This added capacity would supply the equivalent of about 2.5 quads per year of energy. The CEQ estimate for this increment is between 1 and 3 quads per year (4 to 6 quads total when combined with existing dams.)

Electric utilities generally have been hostile to proposals for competing small-scale hydroelectric power facilities, although several, at least, have expressed interest, offering to buy electricity from dam owners at rates that approximate the fuel costs of their own plants.[78] The DOE has developed a program to determine the feasibility of installing or developing hydroelectric facilities at a variety of small dam sites throughout the country.[79]

F. Ocean Thermal Energy Conversion

In many parts of the tropical oceans, there are considerable temperature differences -- as much as 40°F -- between the surface waters and the cold waters lying up to 3,000 feet below. Ocean Thermal Energy Conversion (OTEC) systems exploit these temperature differences to operate turbines which then drive electric generators.[80]

In the so-called "closed-cycle" systems presently under development, warm surface water passes through heat exchangers to evaporate ammonia. The ammonia is run through a turbine generator and is condensed by cold water brought up from below. The electric power produced by floating OTEC machines would either be brought ashore using underwater cables, or used at sea to produce fertilizers, aluminum, or other energy-intensive products.

The size of the renewable OTEC resource base available to the U.S. is not yet well determined, but the maximum amount might be determined by ecological or other considerations, such as the need to prevent any possible climate changes or alterations in ocean-flow patterns. The Department of Energy has identified several areas in the Gulf of Mexico where total installed OTEC capacity could reach 200 to 600 thousand MWe

(500 to 1500 plants).[81] If this many units were finally installed and operated on a base-load basis, they would generate 1.5 to 4 trillion KWh per year, the larger figure being about twice total U.S. electricity consumption today. This would supply the equivalent of between 15 and 40 quads of energy annually. The CONAES Solar Research Group has estimated the maximum OTEC contribution at 1.6 quads by 2000 and 3.9 quads by 2010.[82] CEQ estimates the maximum contribution at between 1 and 3 quads by 2000, and between 5 and 10 by 2020.

The federal program for developing OTEC power systems calls for the construction of progressively larger experimental machines, ending with the demonstration of a 100-MWe unit by the mid-1980's. During fiscal year 1979, a 1-MWe engineering test facility, designated OTEC-1, is to be built. Later, two distinctly different 10-MWe experimental machines are planned to demonstrate the overall feasibility of full-scale units.

Among the major engineering obstacles to be overcome in the development of economic OTEC machines are designing and constructing large heat exchangers, controlling of "biofouling", preventing corrosion, and designing and building a 3,000-foot cold-water pipe. According to DOE, however, there has been recent encouraging progress in demonstrating very efficient heat exchangers and in solving the related problem of slime control.[83]

In addition to the possibility of climatic impacts and altered ocean-flow patterns, several environmental questions need resolution.[84] They relate to potential toxic effects from corrosion and loss of metals and from the use of biocides and other chemicals that might be released into the oceans during plant operations. Also, marine life from both surface and deep waters will be subjected to changes in pressure and temperature, and to different levels of turbidity, salinity, light, and oxygen. The consequences of these changes are not well understood at this time.

G. Other Renewable Technologies

There are other renewable energy technologies under development which we have not reviewed here. These include tidal power, wave power, and the placement of large photovoltaic arrays in space from which electricity would be beamed back to earth using microwaves (Satellite Solar Power Station). The technological and resource uncertainties affecting these applications are sufficiently great at this time that we have not included them within this report. This is not to imply, however, that further research and development will not show them to be viable sources of substantial amounts of energy some time in the future.

H. Energy Storage

The availability of inexpensive and reliable methods for storing energy would greatly facilitate the development of a solar economy.[85] It would broaden the range of solar applications, improve the economics of solar technologies, and reduce the need for conventional fossil fuels as backup. The most critical storage needs are in transportation, heating and cooling of buildings, industrial processing, and electric power production.

Lowering the manufacturing costs of photocells, wind turbines, and flat plate collectors, while certainly necessary, will not in itself guarantee technical and economic viability. The intermittent nature of the solar resource, and the consequent need for reliable storage systems, must be fully recognized and planned for.

There are numerous ways to store energy. They range from straightforward thermal storage in water to electrical storage using large, superconducting magnets. The most important techniques now under development include batteries and other electrochemical processes, as well as chemical and thermal technologies, and mechanical and magnetic storage systems.

In its energy storage program, the Department of Energy is supporting the parallel development of several options for each end use needing storage.[86] For ground transportation, it is working on improved batteries of varied designs for use in electric vehicles in the early 1980's. These vehicles have the obvious advantages of emitting no direct air pollution and of being compatible with emerging solar technologies such as photovoltaics and wind turbines. The overall program goals are to develop batteries of high energy density five times present values and high power (twice present values) at a third of present costs. To gain experience and encourage the use of electric vehicles, DOE plans to order 400 of them in 1978, 600 in 1979, and 1,700 in 1980. A total of 7,500 vehicles are scheduled to be ordered through 1984.

Batteries, of course, also have a wide variety of stationary uses. Photovoltaic and wind systems, whether in centralized or on-site applications, will need the kind of energy storage for which batteries are well-suited.

Energy from solar collection systems also can be stored by using several thermal or thermochemical technologies. Thermal storage for heating buildings, using either water or rocks as the storage medium, is well-advanced. A large-scale demonstration of seasonal thermal storage for the JFK Airport in New York was proposed recently.[87] It would use an underground aquifer as the storage medium. During the winter, water from the aquifer would be chilled by existing cooling towers and later used to reduce summer air conditioning loads. Other thermal storage systems under development utilize chemicals such as sodium hydorxide, whose phase change liberates or absorbs substantial amounts of heat.

Hydrogen offers another promising means for storing energy for both transportation and stationary uses. The development of metal hydrides allows the safe storage of hydrogen at ambient temperatures. The technical feasibility of using hydrogen as an "energy carrier" in buildings, planes, vehicles, and domestic appliances already has been demonstrated. The use of hydrogen in fuel cells to generate electricity offers an especially attractive on-site application because of the possibility of recovering the waste heat to help meet hot-water and space-heating needs. The principal remaining obstacles to widespread use of hydrogen are its high production costs and its tendency to embrittle pipes during transmission and distribution.

A variety of mechanical energy storage systems are being investigated by DOE.[88] Flywheels made from fiber filaments and epoxy are being developed for both vehicle and utility usage. The Department plans to initiate the large-scale demonstration of automotive flywheels by 1982. DOE's Lawrence Livermore Laboratory is overseeing the development of regenerative-braking systems for use in Postal Department battery-flywheel hybrid vehicles.

Other technologies for storing energy, primarily for utility application, include underground compressed air, underground pumped storage, and superconducting magnetic storage. In the compressed air energy storage program, air is forced into a large underground cavern and the energy later recovered through the operation of gas turbines. Such a system has just started operation in West Germany. Similarly, water can be pumped to the surface from a large manmade or natural underground reservoir and then allowed to return, through turbines, during peak demand periods. DOE plans to demonstrate such a system in the late 1980's. Finally, electrical energy can be stored very efficiently in the magnetic field of a superconducting magnet. Preliminary work indicates that the optimal storage size for such a system would be in the 1-million to 10-million KWh range, the latter figure equivalent to the output of a large, 1,000-MWe power plant over 10 hours.[89]

III. Solar Strategy: Getting There From Here

A strong case can be made that a national commitment in the 1950's to develop solar technology -- comparable to the one made to develop nuclear power -- would have led to the widespread economic feasibility of solar energy today. Because of the long lead times necessary to perfect energy producing and consuming technologies, major decisions must be made today if solar energy is to be available as our primary replacement source for tomorrow.

In recent months, a variety of suggestions have been offered to stimulate the federal effort to promote solar energy. They range from a shift in research priorities to larger tax credits, and from increased incentives for local governments to a vast effort, reminiscent of the Marshall Plan, to aid less-developed countries in tapping the rich energy output of the sun.

Following is a review of the possibilities, divided into five categories.

A. Expand Financial Incentives and Eliminate Institutional Barriers

The National Energy Plan (NEP) recognized that the nation's ability to sustain economic growth beyond the year 2000 depends largely on the development of renewable and essentially inexhaustible sources of energy.[90] The NEP contained a number of important financial and institutional provisions to encourage the application of solar energy. Among the measures approved by the House-Senate conferees are the following:[91]

- Tax credits for the purchase of solar- or wind-powered hot-water and space-heating technology for residential application. These credits would start at 30 percent of the first $2000 and 20 percent of the next $8000 for a maximum credit of $2200. The credit would apply to qualifying solar equipment through December 31, 1985.

- Subsidized interest rates for loans for solar heating, hot water, and cooling equipment. In addition, the limits on Federal mortgage insurance would be increased by 20 percent where solar equipment is installed. Also, solar heating systems, both "active" and "passive" would be included as eligible improvements for federal home improvement loans.

- The authorization of $98 million for the purpose of photovoltaic cells by the federal government over a three-year period.

- The authorization of $100 million for the purchase and installation of solar heating and cooling equipment in federal buildings over a three-year period.

- A provision requiring state public utility commissions to forbid, where "appropriate," utility rate structures that discriminate against solar and other renewable energy sources.

Additional measures have been suggested to spur the introduction of solar technology into the marketplace. For example, analyses of the NEP by the Office of Technology Assessment and the General Accounting Office noted these further possibilities:[92]

- Provide additional incentives to install solar heating equipment in new homes, beyond the tax credits already proposed.

- Require that all new buildings be structurally compatible with, and properly oriented for, the later installation of solar equipment.

- Increase loans for small businesses to encourage the use of solar heating and cooling equipment.

- Guarantee loans on solar installations for nonprofit organizations.

- Require consideration of solar technology in federal and state building programs.

- Provide matching grants, revenue sharing, or other incentives to states and localities for plans which emphasize renewable energy sources.

- Develop a more detailed program for equipment certification and installation, and for the legal protection of "sun rights."

- Review utility rate structures for their effects on solar installations and make appropriate changes.

- Designate the Federal National Mortgage Association as a buyer of loans for the installation of solar equipment, and generally provide easier access to the loan market for solar technology purchasers.

- Explore the possibility of using the many federal grant programs in HUD, HEW, DOA, and other agencies to encourage solar development.

- Develop additional incentives to speed the introduction of solar technology into the agriculture sector (e.g., authorize the REA to subsidize solar systems the way distribution lines have been subsidized).

On March 13, 1978, members of the Congressional Solar Coalition (comprised of about 70 Representatives and Senators) introduced a number of bills and resolutions to encourage the use of solar technology. Among them were the following:

-The Solar Energy Bank Act. Would establish a Solar Energy Bank with a $5 billion revolving fund to provide long-term, low-interest loans for the purchase and installation of solar energy systems in commercial and residential buildings.

-World Energy Conference Resolution. Calls for a conference to establish an International Alternative Energy Commission to facilitate the transfer among nations of alternate-energy information.

-Foreign Mission Solar Energy Demonstration Act. Would authorize the demonstration of solar technologies on U.S. diplomatic buildings in other countries.

-Establishment of Renewable Energy Program with LDCs. Would direct the Secretary of DOE to assist the Agency for International Development in its energy programs, with special emphasis on renewable resources in less developed countries (LDCs).

-OTA Future Energy Study. Would direct the Office of Technology Assessment to study the potential for U.S. to convert to solar energy. Feasibility of solar meeting 15%, 30%, and 45% of all U.S. energy needs by the year 2000 would be examined.

-Solar and the Small Business Administration. Would amend the Small Business Act to provide loans to solar and energy conservation companies.

-The Solar Energy Transition Act. This would direct DOE to seek conversion of Federal facilities to solar energy: 1 percent by 1981; 5 percent by 1985; 30 percent by 2000.

Another recently offered proposal would require that solar alternatives be rigorously investigated and, where feasible, preferred whenever a new central-station fossil or nuclear power plant is proposed.[93]

B. Adopt Needed Changes in the Federal Solar Research and Development Program

A number of suggestions have been made for improving the federal government's research, development, and demonstration program for solar energy:[94]

* Some observers argue that the overall level of support for solar energy is not based on a careful review of its potential contributions and benefits. Funding and staffing are said to be too modest when measured by the impacts solar could make in meeting the nation's energy needs.

* Priorities within the solar program are said to be seriously in need of reexamination. Critics claim there is little correlation between budget expenditures and the estimated contributions or estimated needs of various developing solar technologies.

* The solar program has been criticized for emphasizing large-scale solar technology to the detriment of smaller-scale and on-site applications. Big facilities, big expenditures, and multidecade development programs have all characterized the U.S. effort. Yet smaller systems can be developed and tested within much shorter times, and they may prove to be the most cost-effective in the long run.

Research is said to be too skimpy in a number of areas, including those essential to on-site solar facilities. For example, in the DOE research program there appears to be insufficient attention given to solar-actuated heat engines, with little development work relevant to small solar devices. Other technologies for which additional research appears to be of high priority: community-size systems, small windmills, passive solar heating and cooling systems, and on-site photovoltaic total energy systems.

In general, it is argued that more attention should be paid to determining the optimum scale of each solar technology under development, judging by its potential and by its technological and other limitations. For example, many experts have concluded that, when measured by the potential size of the resource and the importance of liquid fuels to the economy, the federal biomass program is too limited in both funding and overall scope.

A recent report of bio-energy specialists concluded that even under optimistic conditions, the existing federal research and development program by the year 2000 would increase the use of biomass by no more than the equivalent of 250,000 barrels of oil per day, about 1.4 percent of present U.S. oil demand. They also concluded that a more aggressive program could lead to many times this amount. The report recommended that an intensified national biomass energy effort be promptly developed and implemented. In addition to more research and development, a greater effort is required to understand the possible adverse environmental impacts of increased biomass production on both terrestrial and oceanic ecosystems.

A similar need has been expressed for a more forthright initiative to develop wind power. For example, it has been suggested that the Department of Energy develop a wind program along the lines of its hydroelectric power program by constructing thousands of megawatt-scale windmills on the Great Plains to provide electricity for irrigation and for midwestern cities.

Another proposal is that DOE foster a demonstration program for solar electric technologies similar to those for solar hot water and space heating.

Finally, a number of observers have said that increased attention should be focused on methods for integrating solar technologies into existing energy supply systems.

C. Institute Price Reform for Competing Fuels

An important barrier to the introduction of solar energy is the artifically low pricing of competing fuels. In the past, consumers of oil, coal, and gas have been subsidized through systems of price controls and through unpaid environmental and national security costs. Prices of oil and gas, artifically controlled at less than replacement values, have led to excessive overall energy consumption and waste. They also have resulted in market distortions among competing fuels. These points are clearly recognized in the National Energy Plan, in which replacement-cost-pricing is one of the fundamental principles.[95]

However, remaining subsidies and related advantages for nonrenewable energy sources militate against the use of solar technologies. They include a number of tax subsidies and credits for energy producers and a reduced-premium insurance program for the owners of nuclear power plants, as well as the pricing of energy at levels less than replacement costs. According to one analyst, without this full range of subsidies, solar space and water heating in Southern California would be competitive with, or less expensive than, Alaskan natural gas or nuclear power by 1985. With existing subsidies, however, the costs for a homeowner using solar will be about $150 per year more than if he used Alaskan gas.[96] More difficult to quantify are those unpaid costs that take the form of risks to the global climate from burning fossil fuels and to the national security from the reliance on imported oil and gas and the spread of nuclear technology.

In the case of electricity, existing utility rate structures usually reflect average costs of all power presently generated rather than the higher, incremental costs of electricity from new power plants. The adoption of incremental (i.e., replacement) cost pricing by state public utility commissions would give consumers more accurate signals about the rising cost of new energy supplies. This, in turn, would make conservation measures and solar energy technology more economically attractive.

But solar equipment faces other market disadvantages even when compared to accurately priced energy from new electric power plants. Utilities are able to finance new plants at lower borrowing rates and better terms than those available to homeowners. Power plants enjoy tax-reducing benefits not available to homeowners, such as investment tax credits and the option to depreciate capital investments. In order to partially offset these factors, the National Energy Plan has proposed tax credits for residential consumers who install solar heating and hot water equipment.

To the extent that continued efforts are made to price competing fuels fairly, taking into account environmental and security risks as well as purely economic factors, the inherent competitive advantages of solar energy will be made clearer and it will become an attractive option sooner.

D. Develop the Solar Market Available in Less-Developed Countries

An aggressive U.S. program to assist in the deployment of solar technologies in developing countries could directly help those countries meet their energy, food, and development needs. At the same time, it could assist the growth of a sufficiently large world market for solar equipment to justify mass production in the U.S. and elsewhere, with consequent cost reductions for everyone.[97]

For example, some have suggested a dramatic, multibillion-dollar aid program to bring solar technologies to these countries as the cornerstone of U.S. efforts to assist the world's poor, help protect the global environment, and reduce the risks of pollution and nuclear proliferation. Supporters of such a program note that much of the aid money would be spent in the U.S. as domestic manufacturers increase their production of solar equipment.

Among the many advantageous technologies applicable are small hydro-electric dams (which in a country like Nepal could stem the damaging deforestation taking place), photovoltaic micro-irrigation pumps (to help boost agriculture in water- and energy-short areas), and low-cost biogas plants (which have proliferated in China and which can be helpful in improving village sanitation, producing fertilizer, and relieving pressure on other cooking fuels).

Small-scale solar technologies have several characteristics that make them particularly well-suited to the needs of developing countries. Being small and self-contained, they can provide energy at dispersed sites without the major expense and delay of constructing extensive transmission or distribution networks -- networks which can cost more than the central energy conversion plants themselves, and which are now typically available only in urban areas.

Being relatively simple in design, decentralized equipment can be built rapidly and provide energy within months, instead of the years required for large systems. Generating capacity can be expanded in step with changing needs. This avoids the large increments of capacity associated with new central power plants. On-site solar facilities also are relatively labor-intensive and thus could help create more job opportunities in these countries.

Through greater use of the solar resource, developing nations could greatly increase their energy self-sufficiency. This would have obvious economic as well as political advantages. Such self-sufficiency is made more feasible because much solar equipment is relatively easy to manufacture, operate, and repair.

In the United States, technologies such as photovoltaic cells, windmills, heat engines powered with solar collectors, or fuels from biomass cannot now compete with our low electric power rates (commonly 3 to 6 cents per KWh). But the price of power from central grids in urban areas of the developing world runs as high as 45 cents per KWh.[98] In those rural areas fortunate enough to have electric power, it usually is produced either by diesel generators or primary batteries, with costs in the range of $1 or more per KWh. In such circumstances, the economics of many solar applications obviously will be more favorable than at present in the United States. And as noted, photovoltaic systems providing power at 10 to 20 cents per KWh or less are expected by 1980.

E. Improve Government Programs for the Purchase of Solar Equipment for Federal Use

The government's intention to demonstrate solar heating and cooling technology in federal buildings was first stated more than two years ago,[99] and an implementation plan was developed in 1977.[100] Memoranda of understanding have been signed by the relevant agencies, but actual installation of solar equipment is seriously lagging. Reasons for the lack of progress should be investigated to ensure that the government will meet the commitment in the National Energy Plan to spend $100 million on installing solar equipment on government buildings.

In addition, the widespread demonstration of solar cells in a range of federal programs appears to have considerable promise. A study of near-term photovoltaic markets found that even with present-day costs, solar cells already can compete with more conventional sources of electricity -- for example, when used in portable radars, portable radios, offshore buoys, and handheld infrared viewers.[101] The study also found that if the price of solar cells drops to about one-half its current level, Defense could purchase over $100 million annually on an economical basis.

In July 1977, an expansion of this analysis was published by DOE's Task Force on Solar Energy Commercialization.[102] This study would stimulate the early establishment of a viable, competitive, photovoltaic industry. Under one purchasing option considered by this study, the Defense Department would replace up to 20 percent of its gasoline-powered generators with 152 MWe of photovoltaic cell arrays, at a cost of about $450 million.

Over a period of 25 years, (i.e., 5 year purchase programs and 20 year life of systems) this would lead to a cost saving to the government of $1.5 billion, or a net discounted benefit of $484 million.

Experts have stressed the need for employing the true marginal costs of energy supplies (rather than average costs) when designing new federal buildings. Then, whenever the life-cycle economics justifies it, solar technologies should be used in constructing federal buildings.

In Conclusion

The sum of the evidence points to the inevitable reemergence of solar energy as a major source of supply for the United States -- just as wood, coal, oil, and gas have been.

Most of this evidence comes directly from the rapid advances already made in the development of solar technologies and their approaching commercial feasibility. Also noteworthy in assessing the future of solar energy are its large natural potential; the strong market incentives at work; the technical ingenuity characteristic of American entrepreneurs; and the outstanding environmental and social advantages of solar options.

Perhaps the key question, then, is that of time. How soon can solar energy come to the nation's rescue? Though no certain answer can be given, it is obvious that the time frame can be narrowed considerably by choosing liberally from the wide variety of governmental actions available and outlined in this report.

Two general objectives suggest themselves:

* Speed up the deployment of available solar technologies so as to maximize the solar contribution to the nation's energy economy in the short and intermediate term.

* Make appropriate plans and commitments to further research, development, and implementation so as to maximize the overall benefits from solar technologies in the long term.

It seems clear that the federal government -- for a time -- must play a strong role in furthering solar development. It also seems clear that some changes and reforms in the federal programs are advisable. In any case, the key policy ingredient is an official and personal commitment to solar energy commensurate with its potential for benefitting the nation.

NOTES

1. I.J. Bloodworth, et al., "World Energy Demand to 2020," Energy Research Group, Cavendish Laboratory, University of Cambridge, Published in World Energy Resources 1985-2020 (New York: IPC Science and Technology Press, 1978).

   While this report reviews the potential for solar energy, we must not lose sight of the equally important role energy conservation must play in our energy future. The number of studies concerned with the importance and potential energy conservation is enormous; the following papers should provide an introduction to the subject: Craig B. Smith, ed., Efficient Electricity Use (New York: Pergamon Press, Inc., 1976); Dennis Hayes, Energy: The Case for Conservation, Worldwatch Paper 4 (Washington, D.C.: Worldwatch Institute, 1976); Energy Policy Project, A Time to Choose: America's Energy Future, (Cambridge: Ballinger Publishing Co., 1974); Energy Conservation, Hearings before the Committee on Interior and Insular Affairs, U.S. Senate, Parts 1 and 2, Serial No. 93-7, 1973; M.H. Ross and R.H. Williams, "Energy and Economic Growth", Published in Achieving the Goals of the Employment Act of 1946 -- Thirteenth Anniversary Review, Joint Economic Committee, U.S. Congress, August 1977; Lee Schipper and Joe Darmstadter, "The Logic of Energy Conservation", Technology Review, January 1978.

2. Workshop on Alternative Energy Strategies, Energy: Global Prospects 1985-2000, (New York: McGraw-Hill Book Co., 1977); Central Intelligence Agency, The International Energy Situation: Outlook to 1985, ER 77-10240 U, April 1977; Pierre Desprairies, "Wordwide Petroleum Supply Limits", Institute Francais du Petrole, and W.T. McCormick, Jr., L.W. Fish, R.B. Kalisch and T.J. Wander, "The Future for World Natural Gas Supply," American Gas Association, Both papers published in World Energy Resources 1985-2020 (New York: IPC Science and Technology Press, 1978).

3. Other potential sources of energy for the United States include oil shales, tar sands, and geothermal energy. The development of shales or tar sands entails major technological and economic uncertainties and the expanded use of either would pose problems (e.g., climate modification) similar to those posed by coal. Geothermal energy, at this time, appears to be a useful but geographically limited energy resource. For a recent review of unconventional approaches to fossil fuels see: Thomas H. Maugh II, "Oil Shale: Prospects on the Upswing ... Again," Science, 9 December 1977; Thomas H. Maugh II, "Underground Gasification: An Alternate Way to Exploit Coal," Science, 16 December 1977, and Thomas H. Maugh II, "Tar Sands: A New Fuel Industry Taxes Shape," Science, 17 February 1978.

4. Energy Policy and Planning, Executive Office of the President, The National Energy Plan (Washington, D.C.: Government Printing Office, April 1977).

5. National Academy of Sciences, Mineral Resources and the Environment, 1975; Oak Ridge National Laboratory, Environmental, Health and Control Aspects of Coal Conversion: An Information Overview, Vol. 1 (ORNL/EIS-94) and Vol. 2 (ORNL/EIS-95), 1977; Energy Resources Company, Inc., Environmental Research Needs for Coal Conversion and Combustion Technologies, Prepared for CEQ, December 1976; C.F. Baes, Jr., H.E. Goeller, J.S. Olson and R.M. Botty, The Global Carbon Dioxide Problem, Oak Ridge National Laboratory, ORNL-5194, 1976; National Academy of Sciences, Energy and Climate, Library of Congress Catalog Number 77-83238, 1977; Report of the Nuclear Energy Policy Group, Nuclear Power: Issues and Choices (Cambridge: Ballinger Publishing Co., 1977); Mason Willrich and Theodore Taylor, Nuclear Theft: Risks and Safeguards (Cambridge: Ballinger Publishing Co., 1974); General Accounting Office, Nuclear Energy's Dilemma: Disposing of Hazardous Radioactive Waste Safely, EMD-77-41, September 9, 1977; A. Lovins, Soft Energy Paths: Towards a Durable Peace (Cambridge: Ballinger Publishing Co., 1977); John P. Holdren, "Hazards of the Nuclear Fuel Cycle," Bulletin of the Atomic Scientists, October 1974; Larence Berkeley Laboratory, Lawrence Livermore Laboratory, and University of California (Berkeley), Distributed Technology in California's Energy Future, a preliminary report to the Office of Environmental Policy Analysis of the Energy Research and Development Administration, LBL 6831, September 1977; Charles J. Ryan, "The Choice of the Next Energy and Social Revolution," A.P. Sloan School of Management, Massachusetts Institute of Technology, 1977; Theodore B. Taylor, "Low Cost Solar Energy," Princeton University and T.B. Taylor Associates, Paper presented at the International Scientific Forum on an Acceptable Nuclear Energy Future of the World, November 1977; U.S. Congress, Senate Committee on Interior and Insular Affairs, Alternative Long Range Energy Strategies, 94th Congress., 2nd Session, December 9, 1976; A. Lovins, "Soft Energy Technologies," (working title), to be published in Annual Review of Energy, Volume 3 (Palo Alto: Annual Reviews, Inc., 1978); Nigel Forman, "A Fuel Policy for Posterity", New Scientist, 16 March 1978.

6. Frank von Hippel and Robert H. Williams, "Toward a Solar Civilization," Bulletin of the Atomic Scientists, October 1977; Denis Hayes, Rays of Hope (New York: W.W. Norton & Co., Inc., 1977); A. Lovins, supra note 5; Theodore B. Taylor, "Prospects for Worldwide Use of Solar Energy," Princeton University, December 19, 1977.

7. F. Von Hippel and R. Williams, supra note 6.

8. The solar energy falling on the lower 48 states is about 700 times present annual fuel use. Therefore 1% of our land intercepts about 7 times our energy needs. At a collection efficiency of about 1/7 (14%), we could meet these needs in principle.

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