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Solar Energy: True God or False Prophet?

by BRUCE MURRAY

Solar energy is not a "Johnny-come-lately" subject at JPL. Members of the staff anticipated the first public recognition in 1973 of the energy crisis. Several years before, they had identified technologies developed for space use—particularly silicon panels used to convert sunlight into electricity for spacecraft—which could provide important energy uses on the ground, if they could be manufactured much less expensively. A pioneering program was started early and has grown now into a major national activity.

Energy research and development—especially solar energy research and development—now account for about one-seventh of JPL's total activity. Because solar *electric* energy is not yet commercial, an appropriate industry does not exist. So it makes sense for JPL as an advanced technology laboratory working under federal sponsorship to try to create new solar technology and identify how it might fit into new energy production and consumption patterns in the future. Surely, it is a proper role for JPL as a part of Caltech to be responsive in this way to important and practical national needs.

I am not going to make predictions about the future degree of solar energy utilization. I do not believe that is possible. About the only thing that is highly probable is that there will be a massive change in the sources of energy that light our rooms and heat our buildings. Beyond that, technological development is quite open, and therefore the proper posture of the United States is to pursue a variety of diverse possibilities rather aggressively, letting the "strongest" win, so to speak, down the road.

We are all aware that the use of energy throughout the United States and the world has been growing at a very rapid rate, primarily through the greatly increased use of oil burned to produce electricity. Oil is a limited natural resource for the whole world, and we are going to "peak out" in its production around the end of this century.

THEORETICAL POTENTIAL VERSUS PROBABLE COST OF SOLAR ENERGY

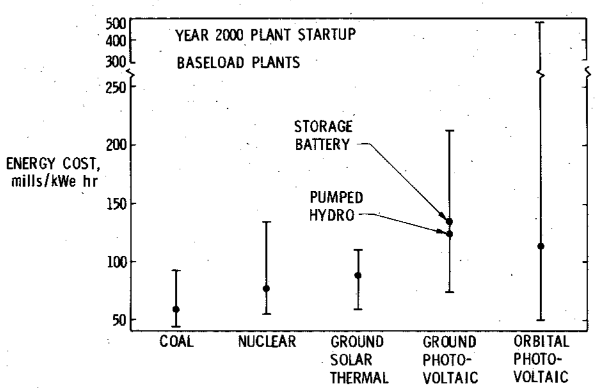
Could solar energy provide enough electricity and heat to take care of the energy needs of the country, or of significant fractions of it? Theoretically, yes. For example, if appropriate kinds of solar collectors were installed on every roof in the San Fernando Valley, most of the electricity and most of the heat required for that whole area could be generated.

But if we have an energy problem and solar energy can at least theoretically supply a significant amount of what we might need, why isn't it national policy to place its development as our highest priority?

The answer comes from an analysis of what it will cost. Because electricity and gas are distributed by utilities and heating oil is sold by large corporations, the economics they face in making new investments in energy systems are very important to what decision actually will be made. Hence, there is considerable effort at present to forecast the costs and other factors that energy supply institutions will actually face in the next several decades.

The illustration above shows one such attempt. This graph (which exhibits a strange-looking scale because it doesn't start at zero and is compressed at the top due to the scatter of the data) was prepared by JPL people who believe in solar energy production. So it is

PLANT ENERGY COST



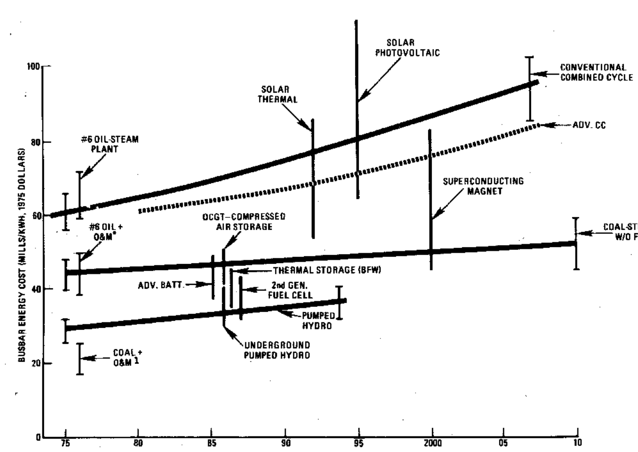
certainly not negatively biased. The units here are the cost of energy in kilowatts per hour. Fifty units or so are assigned for coal. The figure for nuclear is a little higher. Ground-based solar-thermal electric is comparable to nuclear. Photovoltaic production of electricity, which is the program in which JPL is most heavily involved at the present time, is somewhat higher yet. And finally, space power (orbital photovoltaic) could easily cost ten times as much as the ground sources. In this analysis, done by a group that is certainly concerned about the potential of solar, space power doesn't compare terribly favorably.

For comparison, at the right is a portion of a graph prepared by a very reputable national company. They considered quite a variety of technologies in order to try to develop a recommended "investment" strategy for the federal government. Their graph shows the same units along the vertical axis. The horizontal axis is now time, and it refers to when each new technology might be introduced. The solar-electric costs shown here are not much higher than those of JPL; the unit cost of electricity by solar would be perhaps a factor of two higher than it appears to be by coal. Yet that leads this company to recommend a massive exploitation of coal to provide both electricity and heat for the country as oil runs out; solar energy was not deemed very significant.

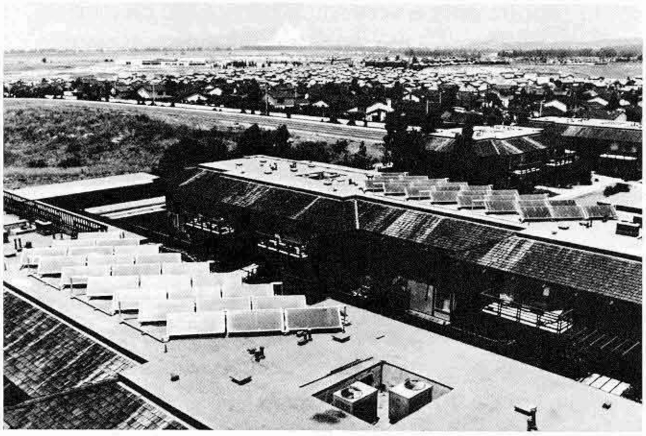
Their reasoning about how useful the billions of dollars that the government is going to invest in new energy technologies depends in part upon how much of a market those technologies finally capture. Because of the difficulty of providing storage or additional base electric load supply in conjunction with conceivable solar electric generation, they assumed solar energy would capture only a very small part of the electric power market, and even then, only at a distant time in the future. Hence, solar electric technology was just not attractive even though the direct cost differences were within a factor of two of, say, coal. They did not envision how solar-electric could fit in practically since solar-based electricity is only produced when the sun shines.

Thus, there really is a national debate revolving around a genuine issue of whether solar energy can be competitive in terms of what are called "utility" costs. This basis of economic comparison attempts to estimate what a utility would have to pay to install and use such technology, and therefore what they would have to charge the user—You.

Now, I am going to argue that these costs and this way of analyzing the situation may not be broad enough to reach sound national judgments. In fact, solar-electric development may be a very important option for the future because there is more to consider than just the cost that may be projected for the utility to pay in a totally unconstrained situation. What is really involved is the *total* cost that society pays, which includes pollution, health, and many other effects. I am also going to argue that, despite all our talk, we are not now operating as a free market for energy supply; we are headed in a direction in this country which may make it impossible in the future for individual companies, or even cities—much less individuals—just to go out and buy energy in the marketplace. Instead, we may be moving toward an allocated society, and if so,



Utility cost versus likely time of first commercial operation for a number of potential new electric-generation technologies, as estimated in a recent federally funded study.



Simple collectors of sunlight are used to heat water in a housing development in El Toro, California.

that also invalidates the utility differences. A third factor is that in some places like California solar energy may fit in very well. In other parts of the country that may not be the case.

SOLAR TECHNOLOGY

How do you capture solar energy and convert it into heat or electricity? First of all, solar energy comes in two forms: direct—sunlight, which can then be used to heat or generate electricity; and *indirect*—wind energy and hydropower, for example.

I am going to discuss the direct forms. With collectors, sunlight can be used directly for heating or cooling. It can be used to enter into chemical reactions with water and other substances to form essential chemicals (hydrogen and ammonia, for instance), though not competitively at the present time. And finally, sunlight can be used to produce electricity either in the same way we do in space (which is to let it fall on silicon or other materials that convert the light directly to electricity) or to collect and focus the sunlight to heat and drive a steam turbine or some other device that converts heat energy to electricity.

Let's run through the technologies, starting out with solar heating. In a housing development in El Toro, JPL and the Southern California Gas Company have been experimenting with simple collectors of sunlight to heat water. The heated water feeds into the hot water system for an apartment building under study, reducing the amount of gas required for hot water heating. This is one of the simplest, easiest, and earliest utilizations of solar heating in California.

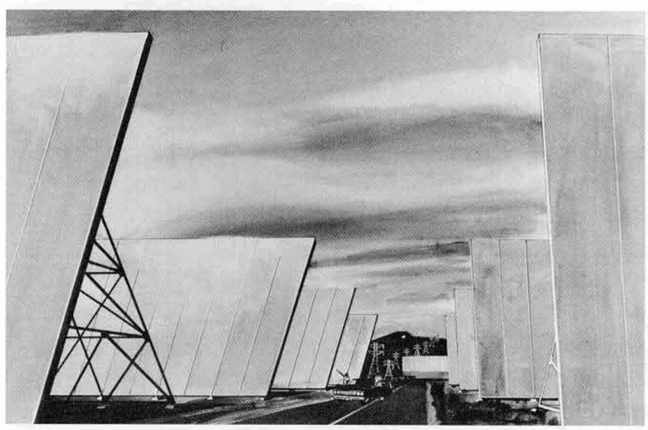
Another type of solar heating now developing (it has been done for years in a small way, but it appears now that it may have applications throughout the United States) involves placing similar collectors on rooftops to heat water which is then used to heat the air to heat the house. These collectors generally would be supplemented by gas or electrical heaters to provide for times when there is not enough sunlight to keep the water (and air) sufficiently hot.

Solar heating is also being used for dehumidifying office buildings, drying agricultural products, and for some industrial processes that need relatively low temperature heat.

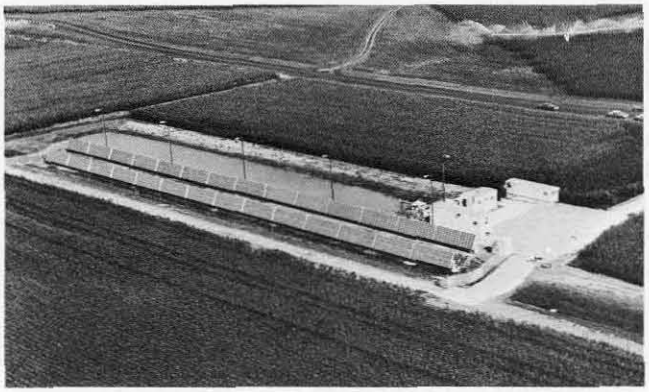
These kinds of applications are all decentralized. There is no big steam plant at the center. It's all done at the site—at the residence, at the apartment building, at the office building, or at the factory. The solar heat energy supplements, but does not replace, gas or fuel oil or utility electricity because there obviously can be cloudy days or conditions that will prevent this kind of system from *always* meeting the needs of the users.

The other major method of using the sun to convert its energy to electricity is by using a "Power Tower"—a prototype system being seriously considered for construction near Barstow, California. This approach would utilize a field of mechanically driven mirrors to reflect the sunlight up to a single focal point, which becomes very hot. That heat is then used (instead of coal or oil) to run a conventional steam turbine.

Such a complex system is very expensive and only becomes attractive on a substantial scale. An alternative method would be to take a lot of smaller collectors, each with its individual devices to transfer converted



Large fields of photovoltaic cells like those in spacecraft may some day serve as small electrical power plants.



On a Nebraska farm, photovoltaic cells convert sunlight to electricity, which is used to run irrigation pumping.

sunlight to electricity, and build up an array. There are advantages of scale in such a large system.

The attractiveness of smaller collectors is that they can be built in an assembly line and installed in modular fashion and begin to produce electricity shortly after manufacture. Hence, the financial risk of long construction delays that any large system (such as nuclear or the Power Tower) has is alleviated; return on investment can be obtained quickly and the system permitted to grow naturally to its most efficient size. There are limits to the application of economies of scale in the energy business. These are only gradually being defined in nuclear energy and are quite uncertain for future solar-electric applications.

A third way to accomplish the same thing is to use photovoltaic cells like those in spacecraft, which should be relatively inexpensive in the future. One would simply aggregate large fields of them to build up what amount to small electrical power plants. But, even though they take up a large area to collect sufficient sunlight, they will still equal in total power output only a small oil- or coal-fired power plant.

Photovoltaic cells can also be used in smaller and dispersed aggregations at the point of use. In Nebraska, for example, sunlight is converted to electricity with such cells, and that electricity is then used to run agricultural irrigation pumping during the day when the sun is out. It can, of course, be supplemented by regular powerline electricity coming from a local utility.

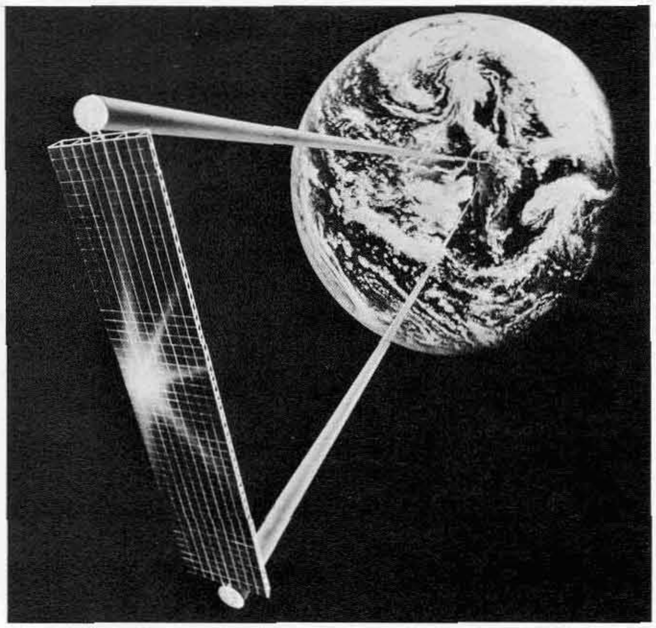
Going to even smaller sizes, there are aluminized collectors, each with an evacuated tube in which steam is generated by the heat of the sunlight. The sunlight is reflected, and it can run smaller turbines. This is a technology that existed in 1900, incidentally. It is nothing new. One can aggregate these, also.

Silicon cells are round and very thin, because they are sliced off from large single crystals—which is intrinsically an inefficient way to make them. The only way they are going to be really useful in the future is if they are much cheaper. There are a good many activities going on right now to learn how photovoltaic materials can be manufactured continuously on a large scale.

In general, everything I have discussed here is low technology. Compared to flying a rocket to Uranus, or compared to the complexities of the breeder reactor, solar-electric technologies are relatively simple and straightforward.

Of course, the electricity from the devices is only produced when the sun is out. Therefore, either there must be on-site storage to provide electricity at other times, or the facility must be tied into a central utility —that is, have an electric wire from the local utility, which is providing base load electricity from burning coal or some other method. One of the reasons the graph on page 5 showed solar as so unpromising a return on the investment is because it is not imagined that it can ever operate entirely by itself. It will always have to operate in conjunction with other *reliable* kinds of sources of electricity. And that runs the cost up.

One concept of solar technology that has received



A 75-ton space power station (25 x 5 km, with a 1-km antenna) could produce 10,000 megawatts of electricity.

POLLUTANTS
CENTRAL POWER PLANTS per MWe per year

	AIR	WATER	SOLID
SOLAR THERMAL*	~8 tons PARTICULATES, NOx, CO	-	-
PHOTOVOLTAIC*	~11 tons MOSTLY PARTICULATES	~2 TONS MOSTLY C. O. D.	-
COAL STACK SCRUB	30-100 tons OF PARTICULATES, NOx, SOx, HYDROCARBONS, CO, METALS	UP TO 55,000 tons ACID; UP TO 8 tons SUSPENDED COAL; UP TO 5.4 tons SLUDGE; NO DATA ON ORGANICS, etc.	1875-2316 tons, NON-RADIOACTIVE SOLIDS
NUCLEAR PLUTONIUM LWR	~1.65 tons NOx, SOx; 4.7-600 curies OF RADIOACTIVES	260-4230 tons OF NON-RADIOACTIVES; 0.1-4.5 curies OF RADIOACTIVES	105,000 tons NON-RADIOACTIVE; ~1600 liters OF RADIOACTIVES

*FROM EQUIPMENT MANUFACTURE ONLY
NO DATA ON SOLAR POWER SATELLITE

a lot of publicity is the space power station. In this case, there would be huge dishes out in space. They would collect sunlight and make electricity, which would then be converted to microwave power and beamed back to earth by an antenna. One drawback is that this conceptual station could be ten miles or more in dimension. Something on this scale could produce large amounts of electricity. It would tap sunlight that does not hit the earth, so it is an additional energy source. Most of the heat and by-products would be dissipated in space and not on the earth, and that has some value. But the costs would be enormous, and they are all front-end costs—that is, they have to be paid for in the beginning, like those of the breeder reactor or other very large nuclear developments. In addition, of course, this technology isn't proven at all.

TOTAL SOCIAL COSTS VERSUS UTILITY COSTS

What about pollution? Is solar energy really cleaner than other sources of energy? Indeed it is. Suppose we compare a solar-electric generating system with coal-fired systems (using a stack scrubber, as it is called, to remove the sulfur and some of the other noxious compounds), and also with a nuclear reactor (a light water reactor using plutonium). In this comparison all the air, water, and solid pollutants will be considered including the mining and manufacturing phases. With solar thermal, for each megawatt of electricity generated annually, there will be about 10 tons of air particulates produced, along with minor nitrous oxides. These emissions include what is involved in the manufacture of materials, not just what is involved in using them to produce solar energy. The total environmental effect is one of the social costs about which we should be concerned.

The coal-based system, for each megawatt of electricity per year, produces something like 100 tons of airborne particulates and substantial amounts of sulfur dioxide and nitrous oxides. In addition, tens of thousands of tons of acid can be expected to be released into the water system along with more modest amounts of suspended coal, sludge, etc. In addition about 2000 tons of solid waste is also to be expected. And the federal government is talking about creating thousands and thousands and thousands of megawatts per year of new coal-based power generation. That pollution will be piling up somewhere, either where it's mined or where it's burned.

In the case of nuclear, there are large amounts of non-radioactive solid wastes as well as radioactive tailings from mining uranium, and small, but serious amounts of other kinds of radioactive debris. Those constitute the well-known problem of nuclear waste, but it is important to recognize that burning coal also has very large environmental effects. The total social cost of extraction and transfer, as well as the burning, of coal has to be included in those effects.

I cannot say how much air, water, and solid waste pollution cost in dollars, because we cannot reduce everything to a monetary base, but there is a real cost. There are the public investments involved in these various things. There are a lot of health effects. For example, in coal mining there is black lung, as well as other diseases. There are certain public health effects caused by breathing the material that comes from the burning of coal. Those have direct costs, in terms of health insurance premiums and lost worker productivity. They also have an intangible cost to the people who get the diseases. Even if one can pay the costs of illness, it doesn't make being ill any nicer.

There is also the impact on our resources. There is a limited amount of land. There is a limited amount of water. There is a limited amount of capital. There are things that must be allocated by the society and they have to be accounted for somehow.

We have to worry about climatic effects that may be created by the burning of large amounts of coal. The burning of coal or any other fossil fuel releases tremendous amounts of carbon dioxide to the atmosphere. The global carbon dioxide concentration *is* building up. At some point that will cause climatic effects. We don't know exactly when, but sooner or later it *is* going to be a problem. A climatic effect would be a lasting problem, like the nuclear one.

Another concern about coal is the large amount of sulfur that is burned; much of it ends up as sulfuric acid. Sweden suffered for centuries because England was burning coal and the winds were carrying the acid clouds to Sweden.

Besides environmental and health factors, there are others. For instance, President Carter has been very concerned about the diversion to the production of weapons of nuclear material, and that is a principal reason he opposes the breeder reactor development.

There are genetic effects from radioactive material and also from some of the other pollutants that emerge from burning of fossil fuels. These are all part of the total social costs.

Of course, one cannot quantify those intangible costs. One cannot say how much the environmental damage is worth, or how much a health effect is worth, or how much the use of land costs. Hence, it is argued that we will still have to use utility costs as the guideline for the development of new energy technology.

But I think that is not true. I think the fact is that some economists cannot quantify those costs, and therefore they tend to think solely in terms of utility costs. But the Congress does not, and the President does not. This total social costing by elected officials shows up as government regulation and taxation policies. So there is, in fact, an attempt made by the political process to grapple with things like strip mining of coal, air pollution standards, and nuclear waste licensing requirements. The intervention of the federal, state, or local government, in the form of regulation, is really an attempt to respond to all those factors that cannot be dealt with strictly by the marketplace cost of a new energy technology. This is a very imprecise process, and it becomes very confused. The process gets mixed up with other social questions such as redistribution of income, and overall doesn't work very precisely by some people's standards. But it is there.

Oddly enough, the people who are developing new energy technology have not always acted as if they understand the political process in reconciling public attitudes about total social costs. The nuclear energy business is an outstanding example, I think, because the arguments for early widespread introduction of nuclear power reactors were based strictly on utility costs. It was recognized, of course, that there were side effects from waste disposal and, hence, widespread concern about pollution and exposure to radiation, and also about the possibility of sabotage or illicit weapons

TOTAL SOCIAL COSTS

UTILITY COST

Cost of materials, capital, labor, fuel, taxes, insurance, etc. for every system
- Central plant
- Transmission
- Distribution

RD&D

Public investment for research, development and commercial demonstration

HEALTH

Cost of public and occupational health due to:
- Mining
- Fuel upgrading and transmission
- Material acquisition
- Construction
- Plant operation
- Final waste disposal

RESOURCES

Resources consumption such as:
- Material
- Fuel
- Manpower
- Land
- Water
- Capital
- Communication frequency
- Geosynchronous sites, etc.

ENVIRONMENTAL

Environmental residues such as:
- Gaseous
- Liquid
- Solid
- Waste heat
- Others

OTHER

Sabotage, blackmail
Material diversion to weapons
Time distribution of impacts
Local or global climate effects
Acid rain
Genetic effects
Non-renewable material use
Land use
Construction impacts

production. But since nobody knew how to confidently quantify those things, they tended to be ignored by the planners—including those of the government and the utilities. What has happened instead of early widespread use of nuclear reactors is that legislation was passed that makes it very difficult to build nuclear plants. So the *real cost* to the utilities of a new nuclear plant is now enormously greater than that forecast ten, fifteen, or twenty years ago. I feel there may be genuine parallelism in the current "bandwagon" for rapid expansion of coal utilization as the panacea for our energy needs.

It is particularly significant, I think, that the solar technologies on the ground have very few bad side effects from the point of view of society. That is my first point in trying to respond to these cost comparisons—that the "utility" cost comparisons are insufficient and that, in fact, society really does try to deal with total social cost. It may appear now that coal is significantly cheaper, but if the mining, transportation, and combustion of coal is increasingly deemed to be harmful or undesirable, then the projected "utility" costs may mean little if the government puts air pollution standards and extraction and transportation regulations on coal that require expensive additional technology to meet.

Another example will show what happens when total social costs get involved with other social questions—like redistribution of income. There has been a bitter battle going on in the Senate over natural gas pricing—a keystone of President Carter's energy bill. The argument is whether or not the government should continue to regulate the price of natural gas that is moved between states. Natural gas used to be an unwanted by-product of oil. It was burned off at the wellhead. It was free initially and eventually became useful as an additional energy source. Gas became regulated primarily for market purposes having to do with the needs of the suppliers for predictable pricing. Suppliers now want to deregulate natural gas (which means to let its cost rise to what it should cost compared to other sources of energy—a factor of two or three more than its present cost) and say, "Higher prices will be an incentive to find more natural gas, which will increase the supply." Those representing gas importing consumers say in answer, "No. Allowing the price to go up is in effect a regressive tax, which means everyone has to pay for it, and that is unfair to the people with the least income. Instead, we should allocate it in some fashion."

Both kinds of statements miss the energy reality this country faces. I feel that the price of natural gas should be increased to its energy replacement cost so as to *cut down* on the use of natural gas because there is a finite amount of it. There is no doubt that eventually we will use every last bit that can be extracted. Only the time scale is uncertain by a few decades. As the price goes up, that will tend to cause people and institutions to use less and to look for alternatives. And, as the price goes up, it makes other sources of energy—such as new solar technology—more attractive for investment and development.

ENERGY ALLOCATION INSTEAD OF FREE MARKET PRICING

That is the right reason to let the price of gas go up. But that right reason gets caught in the political turmoil, and instead we have this great big, almost theological, debate going on nationally which is really over redistribution of income. What is happening in the United States now, in my view, is that we are abandoning the free market in energy pricing. The market is being controlled, partly by the government, and it is pretty obvious that it's going to *continue* to be controlled. If the availability becomes really rough, we'll ration the stuff; we'll allocate it, because we can't seem to solve this political debate in terms of a national long-term energy policy.

We are moving toward a society in which, at least in the case of natural gas, the free market is not what is governing the energy source used. In northern California, industries have already been told by the local gas company that they cannot have more gas after a certain period of time; they must burn oil or coal. One reason for this approach to allocation is that it is easier for large users to switch to oil. Another may be that there are fewer votes in industry than there are among all the millions of homeowners who use gas. And since there is not enough to go around, the gas company is going to offend the least politically significant part.

I suggest that this process is likely to continue, and as the fossil fuel energy sources become less available, we will move more to an allocation society, governed in the short term largely by the political clout of those people receiving it, mainly homeowners—the most numerous votes.

One thing that would mean is that those company cost analyses from the utility point of view won't really apply, because if you cannot get an essential resource, its hypothetical cost is irrelevant. What really counts is whether a company, city, or other institution that needs to increase its energy consumption has the opportunity to go out and pay with capital for its own *in situ* production capability of, say, electricity from sunlight. If the total cost of that investment is still a relatively small fraction of the total new plant investment, it may be well worth doing.

So, in addition to the need to consider total social cost, we probably will be in a fuel allocation mode as a country. And the outcome will be that seemingly "uneconomic" energy sources such as solar, which could be acquired independently of rationed fuels, may become very desirable in some cases.

TENDENCY TOWARD REGIONALIZATION

In my view, the third part of the argument for solar is that there is a strong tendency toward regionalization going on in the country—and, for that matter, in the world. Quebec wants to secede from Canada. The San Fernando Valley wants to secede from Los Angeles County. There's always a balance between pressures to bring groups together and pressures to pull them apart. I think the repulsive forces seem to be gaining strength, at least in the Western world, which has many implications for energy. This is because the kinds of energy sources we are discussing are the ones that are globally, or at least nationally, integrated. Coal is mined in one place. It is transported to a place very far away to be burned in a very large power plant. The resulting electricity is then carried long distances over transmission lines. Right now that is not much of a problem except when a coal miners' strike serves to remind us temporarily of the interconnectedness. We have a rather strongly integrated society, but the debate on whether or not the Alaskan oil terminal should be here in southern California has interesting overtones. We don't benefit locally much from having that terminal. We have enough local oil that we don't need the Alaskan oil. Should we be the polluted port for billions of barrels of Alaskan oil to flow to our neighbors and fellow citizens elsewhere in the country? If pollution or other effects are sufficiently significant, a serious political issue emerges. There are generally similar arguments in many other parts of the country.

We are moving toward a society in which there will be real shortages of energy resources. And as we do, we must prepare for rather different approaches regionally. I think southern California and Arizona and some other states will find solar energy a particularly attractive option. However, some other parts of the country that are poor in naturally occurring energy sources and also low in available solar energy are in for a tough time. There is already a tension developing between the frost belt and the sun belt.

But that is just the tip of the iceberg. If we have the kind of energy shortage that is forecast (and seems likely to me and to many others), we may be in for a political period of very great regional tensions and differences. That fact will change the economics and the decision-making. And those areas that have local resources like solar will tend to use them.

OTHER BARRIERS TO INTRODUCTION OF SOLAR ENERGY

There are some other barriers to utilization of solar energy, and I think it is important to understand them. Some can be modified, but others are pretty persistent and deep. One genuine barrier is the investment that has already been made in pipelines, electrical transmission systems, and large-scale power plants. Money that is spent is spent. It becomes an existing resource. If we go another twenty or thirty years along the direction of ever-increasing generation of electricity from fossil fuels, we may be in an irreversible posture. There may be a point of no return when the capital outlays required to introduce a really different energy technology like solar-electric simply exceed what the then more brittle economy can muster. We certainly aren't there yet, but it is difficult to set time scales. In any case, previous investment dominates the future, and there will come a time when the U.S. probably will lose the ability to loop back in and go, for example, to a solar-based economy.

The second barrier to the use of solar energy is that it cannot come into play on a large scale until the cost of energy, whether it is in the form of gas, fuel oil, coal, or electricity, is at its real replacement cost. If a new war breaks out in the Middle East and really shuts off the Arabs' oil to the U.S., the national imperative would require a much more realistic fuel pricing policy regardless of income redistribution arguments. That unfortunate situation, nevertheless, would provide real economic incentive for the development and utilization of solar technology. If a disruption to the supply of imported oil doesn't happen (and I surely hope it doesn't because of war), but we do continue relentlessly to import more and more oil, the eventual economic effects will be so serious that we really may not have the capability to recover and to play the dominant role in

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Solar Energy . . . *continued from page 11*

world affairs that we have so far in the 20th century.

The third barrier to the introduction of solar energy is the pricing policies of the utilities. Utilities are, in fact, controlled by the elected officials of the states. They are not run by a Machiavellian group of top-hatted, fat business men from Wall Street, but by a bunch of people representing the regions in which they live. They reflect the attitudes of the people who run those states. Their present attitudes, for various reasons, do not tend to encourage—and in some cases tend to discourage—the introduction of solar energy. For example, in the case of gas, or any other resource which needs to be conserved, there should be a rate system that reflects the fact that as you use more, that extra increment of gas costs a lot more. Such a price structure would provide an incentive for developing alternative technologies to avoid having to use that extra gas. Solar-assisted gas water heating would look a lot better under that kind of pricing structure, for example.

The state of California has already made some rather radical changes, including an inverted electrical rate structure, a conservation measure to decrease consumption. Because it taxes the big guy a lot more than the average homeowner, it's an easy political adjustment to make, and it is not surprising perhaps that it is one of the first radical departures from previous policies by the state of California. However, I am hopeful we may see other enlightened changes as well.

I think we will see a lot of differences elsewhere in the country. Some states are going to make it, and some are not. It has happened before. Vermont and New Hampshire used to be leading industrial centers for the United States (using hydro power). They are not now. The South used to be impoverished and downtrodden. It is not now. Some parts of the country are going to get better; some are going to get worse. And it's going to have a lot to do with how intelligently they deal with future energy supplies and current utilization patterns.

There are other important aspects of utility pricing. For example, to produce electricity from the sun on site—at schools, hospitals, factories—arrangements must be worked out for electricity generated to be sold to the utility when it is not used on site, say on holidays and weekends, or when there is otherwise excess capacity. Similarly, the same utility must be able to provide base load at other times. Hence, sometimes the excess electricity will have to flow the "wrong" way down the wire, back into the utility company, where it can be distributed and used elsewhere instead of fossil fuel plant production. That means the utility companies have to buy it back from you. Right now they have so little incentive that the amount they will pay is unrealistically low. This is a complex technical and regulatory question, but I am optimistic that a suitable incentive system for both the utility and its customers can be arranged if the people of a given region place priority on such an objective.

A fourth barrier to the introduction of solar energy is that solar energy equipment is usually expensive when first purchased. If you want to put in a solar heating system, you have to pay nearly all the cost at the beginning to pay for the equipment. The benefit comes in reduced gas and electrical bills later on. On the basis of "life cycle costing," it may well be quite advantageous, but the average homeowner may not be able to handle that initial investment. So one approach, at least in California, could be to have the gas company lease to you, at a standard monthly charge, the equipment that is required for solar water heating, for example—or maybe for solar space heating, in time. Let the gas company deal with the bankers. Let it deal with the maintenance and the obsolescence of equipment, and let the cost show up as a fixed increment on the monthly bill. That way the utilities, rather than being a barrier to new technology, could be an essential attribute to its introduction. This also is a complex issue because of the many factors the utilities must consider. But it is an option if the society wishes to create appropriate regulatory and tax incentives.

The United States came out of the 1960's deeply polarized and with a profound suspicion of institutions, particularly large institutions. It is ironic that some of the strongest advocates for solar energy are also the most suspicious of large institutions. They are convinced that the large oil companies and the utilities are making a rip-off and that the nuclear industry has the government in its pocket. This very suspicion may do more to inhibit the development of solar energy than anything else, because I feel we have to use the large institutions to get the solar technology in place. We have to involve the utility, rather than make it feel threatened and defensive by the advent of solar energy. Letting the utilities be the institutions to introduce solar energy might well be the most successful way to enhance development of solar energy.

Finally, in listing barriers to the introduction of solar energy, there is the fact that in the building industry there is considerable inertia from labor unions, building codes, permits, etc. A lot of solar energy activity involves both retrofitting old buildings with new equipment as well as incorporating it in new buildings as they are constructed. These techniques require society to overcome a tremendous inertia. It is not because of a negative vested interest. It is not conspiratorial. But people are accustomed to doing things in a certain way. They have specialized skills. They are trained to use them. The changing of that, to introduce something on a large scale like solar water heating, space heating, and electric generation built into buildings, is going to take a lot of time.

I'm not optimistic that change will occur very rapidly unless we can provide positive incentives to the various groups and factions to evolve their ways of doing things. Then the progress could be much more rapid.

SUMMARY

Solar energy utilization in ground systems probably will come in initially as supplements to existing gas and electric systems, and will continue as a part of the energy infrastructure indefinitely in a mixed form. It is not a question of solar *instead* of nuclear, or solar *instead* of coal exclusively. It's a question of what the mix will be, and the solar part of the mix could be quite large. A lot of the deleterious side effects of nuclear and coal could be minimized by bringing in a large component of solar. But it will have to be brought in in a harmonious, synergistic way, not as competing and separate.

If energy—especially electrical energy—becomes not just expensive, but just not available, then solar electric will look particularly attractive. Similarly, if gas were to become just not available, solar water and space heating will look very attractive —almost regardless of cost.

I think some of that is going to happen.

Second, if the society will allow the price of energy, including natural gas, to rise to its replacement cost, the introduction of solar and other new technologies will be greatly expedited. The longer this is delayed, the more difficult it will be to introduce solar. That is a politically tough thing, because everybody pays a gas bill, everybody pays a fuel bill, and a higher bill will not be politically popular. But I feel very strongly that it is in the best interests of our children and our children's children to add a substantial solar component to the total energy mix.

It must be recognized that there *is* a cost trade-off; it *will* mean a higher utility bill to have cleaner, safer energy. It doesn't do any good to use political rhetoric implying that that is not true. It means a trade-off in standard of living. It's a question of the quality of one's life in terms of amounts of material goods versus the quality of one's environment.

I believe the energy problem is going to force this society to face that issue more starkly than any other single circumstance in the coming decades.

Third, the introduction of solar energy will be aided by the constructive evolution of institutions, such as utilities and energy companies, to be part of that process, rather than threatened by it. This, again, is a political problem. It's a case of building an understanding and a partnership among groups of people who right now are not very close together. It's a political challenge, and it can be solved. It also might *not* be solved. The outcome will have a lot to do with how effectively solar energy actually gets into people's homes, into their schools, and their shopping centers.

A fourth conclusion is that solar energy can fit into both a centralized energy society, as we have now, or a more dispersed one. Many energy alternatives cannot. California is particularly well matched to the introduction of solar energy, and therefore it makes sense for California to take an aggressive posture toward the introduction of solar energy. It is in our own self-interest and may well aid the country's future as well.

A fifth conclusion is that whether or not ground solar-electric generation makes sense, the economics of space solar-electric clearly are a long way in the future. Because it has some unique merits, the major technological bottlenecks that make the costs so high should be delineated and a program initiated aimed at their reduction. But I don't think we should look upon space solar energy as a practical element in our future or even that of our children.

The final conclusion then is that solar energy is not *the* true god in the sense that it is clearly *the* solution; it is also not a false prophet. It isn't an illusion. It *could* be a primary energy source for the United States a lot sooner than any of the predictions that you see. But it will not happen by marketplace forces alone. It will not happen if we are divided and polarized, as has been the case with nuclear; that will kill effective solar energy development, I feel. The threat is that we might, as a country, find ourselves with no choice but to go along with high-pollution forms of energy in the future and rule out the benefits that solar might confer.

You can see, therefore, that so far as solar energy is concerned, I am not a Deist, I am not a Theist, but rather I am an Existentialist. Society is going to create its own god in this situation, its own religion. We will, in fact, choose our own pathway. It is open to us to go on a relatively high solar road. It is also open to us to go on a "lower" coal road. What will happen will reflect the preferences, expressed one way or another, of the people of this country regarding their environment, their health, their material standard of living, and their attitudes toward their descendants. □