Chapter VII

THE IMPACT OF SOLAR ENERGY ON U.S. FOREIGN POLICY, LABOR, AND ENVIRONMENTAL QUALITY

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The Impact of Solar Energy on U.S. Foreign Policy, Labor, and Environmental Quality

BACKGROUND

Extensive use of solar energy throughout the world would relieve some of the international stress which results from competition over diminishing energy resources. Solar energy is one of the few energy resources reliably available throughout the world and, to the extent that it can be developed in lieu of conventional energy sources, it can reduce the uncertainties and trade imbalances which have resulted from energy imports.

Moreover, solar energy technology can be implemented without the technical infrastructure and cadres of skilled engineers required to implement most other energy strategies— in developing countries solar energy may provide a technique for converting low-cost labor into low-cost energy. While it is difficult to anticipate how fast solar energy will be introduced into the world energy market, it appears that solar energy's impact is likely to be quite small in the next few decades unless accelerated programs for developing this industry are undertaken.

It is likely that solar energy will grow more rapidly abroad than it does in the United States, since U.S. energy prices are relatively low, U.S. domestic energy supplies are relatively large, and U.S. labor costs are relatively high. However, U.S. policy in solar energy will probably play a critical role in influencing the development of this technology throughout the world: the United States now probably leads the world in the quality of its solar engineering. The United States can influence utilization of solar energy in developing countries through its economic assistance programs and a major U.S. commitment to the use of solar energy for its own use would give a prestige to the field which may attract worldwide emulation. The history of the past two decades clearly indicates that these three effects resulted in a rapid transfer abroad of U.S. interest in fission reactors.

The eventual need to develop renewable sources of energy is beyond serious contention, although there is disagreement about the urgency involved. There are two parts of the problem: near-term depletion of low-cost oil and gas reserves, and the depletion of all fossil and uranium resources over the long term.

Many recent studies have indicated that world demand for oil and gas may exceed supplies by the middle of the 1980's,[2] In the past two decades most of the developed nations of the world and the industrialized sections of developing nations have become heavily dependent on the convenience and low cost of petroleum and natural gas, and consumption rates have become astronomical.

A shortage of indigenous supplies of these fuels has required many nations to import them and in many cases, dependence on these imports is heavy. This dependence *is* likely to increase during the next decade because of the shortage of acceptable alternatives, and the high costs and long construction times needed to convert to the alternatives which become available. The uncertainties associated with importing a

[1] *The International Energy Situation: Outlook to 1985*, Central Intelligence Agency, Report No. ER-77-10240V, April 1977.

[2] Carrol Wilson, Project Director, *Workshop on Alternative Energy Strategies*, the MIT Press, Cambridge, Mass., 1977.

large fraction of a critical material are amplified by the fact that world resources of petroleum are inequitably distributed. The OPEC cartel, for example, controls 68 percent of known world reserves of o i 1, and its Middle Eastern members alone control 55 percent of known reserves.

Coal and other fuels can be substituted for oil and gas even though the use of these energy sources is not as convenient as liquid fuels. The use of coal resources may be limited by environmental problems, transportation costs, and other difficulties. Figure VI I-I indicates that if world energy consumption grows at its current rate, proven world **reserves will** be **entirely consumed** by 2015, If the entire world consumed energy at U.S. consumption rates, world reserves would be depleted by the end of this century, It is, of course, unlikely that production or consumption rates will continue to grow exponentially and new energy sources, such as fusion, may be available to

[1] *Oil and Gas Journal*, Dec 29, 1975

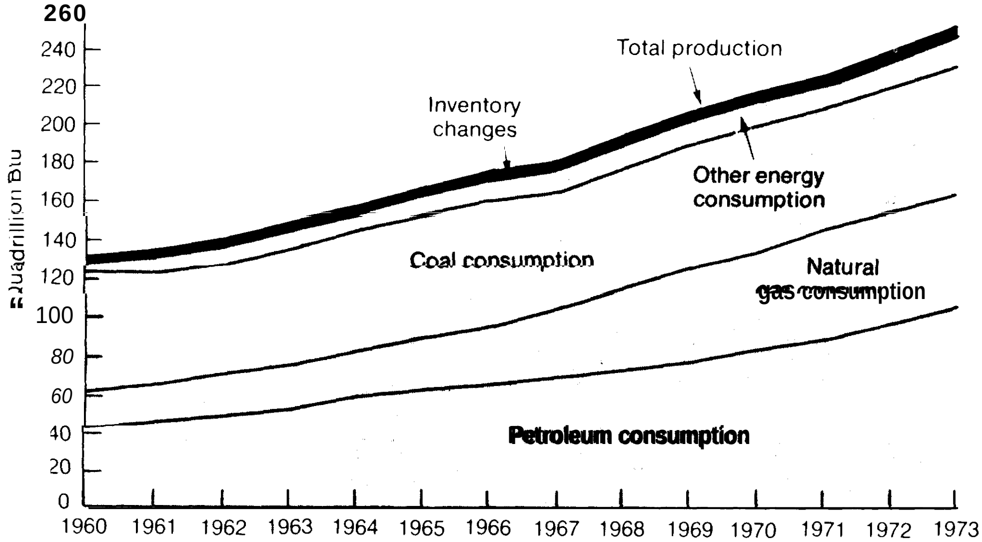
Figure VI I-1 .—World Energy Supply and Demand

Measured World Recoverable Energy Reserves, 1974
I Quadrillion Btu]

Area	Solid fuels	Crude oil	Natural gas	Oil shale and tar sands	Uranium (nonbreeder) [2]	Total
Africa	361.7	526.6	201.7	81.4	1981	1,369.5
Asia (less U. S. S. R.)	2.608.7	2,202.4	432.6	8702	3.1	6,1260
Europe (less U S S. R.)	2,581,5	57.1	153.6	117.0	46.4	2,955,6
U.S.S.R.	3,325.5	333.6	577.9	139.0	Unknown	4,376.0
North America	5,070.9	301.0	380.6	9,111.0	422.7	15,286,2
South America	49.8	311.5	60.6	23.7	11,9	4575
Oceania	459,8	9.4	24.9	9.2	99.1	602.4
Total	14.457.9	3,741.2	1,831.9	**10,3515**	781.3	'31 ,1732

[1] According to the U S Department of the Interior Bureau of Mines North American tar sands and shale 011 reserves may be severely overstate: Development of most of these reserves is not economic at present
[2] Energy content using breeders 60-100 times as great Thorium resources neglected
SOURCE World Energy Conference *Survey of Energy Resources New* York 1974

World Energy Consumption, Production, and Inventory Changes



SOURCE Energy Perspectives 2 U S Department of the Interior, June 1976 pp 11 and 20 provide essentially inexhaustible supplies of energy in the next 20 years, but it is difficult to take great comfort from the available statistics.

World supplies of fuels other than oil and gas are also inequitably distributed Figure VI I--i indicates that nearly half of known world energy resources are located In North America (although the share would be reduced somewhat If oil shale assets are overstated) The United States, U S S R , and Eastern Europe control 73 percent of the known world reserves of coal [4].

There can be little doubt that growing uncertainties about energy supplies will have an Important Impact on international political stability during the next decade intensive efforts will be made to develop domestic resources and to ensure the security and reliabllity of foreign supplies The latter objective, however, would appear to be Increasingly difficult to achieve The effort to assure supplies and the vast transfers of assets between nations which occur in the process, can create economic dislocatlons in developed nations and frustrate the aspirations of less developed nations This, In turn, could lead to restructuring of world alliances There has been speculation, for example, that democratic institutions (in nations such as Italy) may collapse under the weight of accelerating Inflation and recession traceable, at least in part, to energy costs Dr Henry Kissinger has warned that:

> Not since the 1930's has the economic system of the world faced such a test. The disruptions of the 011 price rises, the threat of global Inflatlon, the cycle of contraction of exports and protectionist restrictions, the massive shift In the world's financial flows and the likely concentration of invested surplus 011 revenue In a few countries, al I threaten to smother the once-proud dreams of universal progress with stagnation and despair

The sense of insecurity attached to importing energy resources is magnified by the fact that in most cases supply lines for energy are very long and thus potentially very vulnerable No nation can be comfortable if a commodity on which Its economy depends comes from so uncertain a source Moreover, in any situation where a state or a group of states greatly dependent on Imports can assemble a substantial military capability, a disruption, or threatened disruption, of those supplies carries with It a high risk of International violence It is noteworthy that the U S response to the embargo of 1973-74 included thinly veiled threats of military action

Another potential source of energy-related conflict concerns nuclear proliferation The global spread of civilian nuclear energy has been accompanied by a decline in the number of technological, economic, and time barriers to acquiring nuclear weapons An increasing number of countries are already capable of producing their own nuclear arms The consequences of proliferation are subject to debate, but they are unlikely to be positive from the perspective of U S or global interests. A strong argument can be made that proliferation will jeopardize regional and global stability, increase the likelihood of nuclear war, exacerbate the threat of nuclear-armed, nonstate terrorism, and greatly complicate U S. relations with new (potential or actual) nuclear weapons states. Because securlty concerns are a key incentive to acquiring nuclear weapons, the probability of prolIferation will tend to be greatest in regions with the highest potential for international conflict

In the past, the United States placed major emphasis on aiding nuclear energy development programs around the world In recent years, this program has been tempered by a concern about proliferation, resulting in efforts to tighten export agreements, to prohibit the export of facilities for reprocessing plutonium or enriching uranium, and to discourage foreign transfers of such technology.

The United States, however, is in a weak position if it attempts to discourage the development of nuclear power in nations

[4] Wilson, p 171

where attractive alternatives are not available.

DEVELOPING NATIONS

Less developed nations are likely to be most vulnerable to energy shortages and a steep increase in energy prices. They will be less able to compete for scarce resources and less able to bear the additional financial burdens. (It could be argued that less developed nations will fare better than developed nations, since the less developed a nation is, the easier it will be to return to noncommercial fuels such as dung and wood) Plans for developing an indigenous industrial base and modernizing agricultural methods have already been disrupted by higher energy prices. Many irrigation systems in South Asia, for example, stand idle because the fuels to operate them cannot be obtained.

The economic assistance programs of the developed nations are partly responsible for the dilemma. These programs have in many cases attempted to promote the development of an industrial infrastructure which is as heavily dependent on scarce energy resources as U.S. industries.

The relatively small onsite solar technologies examined in this report should be particularly attractive to developing nations for a variety of reasons:

- These nations typically have not invested in an extensive network of transmission and distribution facilities (equipment which frequently costs as much as the generating stations themselves); onsite technologies could provide power to dispersed sites without the expense and delay associated with building such equipment.

- Onsite equipment does not require an enormous investment of capital in a single project, thereby reducing the overall risk of the investment and avoiding expensive capital-carrying charges during construction.

- The equipment can be built rapidly and produce power within weeks or months, instead of requiring years.

- Major banks are likely to be interested in loans to developing countries for capital equipment which does not commit the borrowing nation to large operating expenses. Solar devices fall easily into this category, while generating equipment based on fossil fuels does not.

- Generating capacity could be expanded flexibly and proportionately to meet growing requirements for energy. Large facilities produce sudden large increments in capacity which are difficult to manage This problem frequently results in prolonged periods of expensive overcapacity

Some of these advantages would be reduced or eliminated if it were necessary to construct a centralized utiilty large enough to meet all energy requirements of the area under the assumption that solar equipment might supply no energy during some period of peak demands There are a number of ways of eliminating the need for centralized backup power in developing countries:

- The facilities requiring energy could simply be shut down when energy was not available — this would reduce labor productivity but would not be as significant in a location where labor was relatively inexpensive

- Many solar applications, such as water pumping, will need no backup in remote areas since storage is very inexpensive

- Small emergency generating equipment could be maintained to provide backup power when solar energy fails. Energy from diesel generators is commonly used in remote villages and is very expensive, but the costs would be more manageable if the devices were only operated a few days each year

Solar energy should also be attractive to the less developed countries on grounds of broad social utilitv

- As a relatively labor-intensive means of power generation (both in terms of manufacture of components and installation), solar energy should help alleviate the endemic high unemployment and underemployment that plague most developing countrles
- Village siting of solar facilities would help raise rural living standards This could, in turn, have the effect of reducing the rate of migration to urban areas in search of employment which is often available only in urban areas because only urban areas have adequate supplies of energy
- Solar energy facilities can be constructed utilizing a variety of materials, many of which may be locally available.
- Developing solar energy would not commit those countries to forms of energy production that they may not be able to sustain because of fuel shortages or the lack of secure funds for operating costs

Solar energy may well become economically attractive in developing nations In many applicat[ons significantly before it does so in the United States for a number of reasons Most developing nations are located in areas where sunlight is plentiful (see figure VII-Z); labor costs–which frequently represent a substantial fraction of the total costs of a solar energy installation — are relatively low; and the cost of competing energy — when it is available— is frequently very high. Table VI I-1 summ a r izes the prices charged ror ectricity in many nations around the world. The information is difficult to Interpret since many governments subsidize the selling price (For reference, the fuel prices alone contribute over 3¢/kWh to the cost of electricity If petroleum is Imported at world 011 prices) The table does show, however, that energy prices in many parts of the world are several times higher than they are in the United States.

Economic comparisons are of no relevance in areas where commercial energy is not available because of long lines of communication, the lack of trained maintenance personnel, or other factors. A recent survey estimated that about 500 million people in the world live in villages without any electric power.[5] About 45,000 American Indians in the American Southwest live in villages without electricity.[6]

The major barrier to all energy sources in these areas, of course, is the shortage of capital resources. Although operating costs are low, solar energy equipment requires a substantial initial investment which most small developing nations will find difficult to raise. Any major program for developing the solar resource in these areas will probably require external financial and technical assistance. As noted above, it may be easier to obtain financing for many small, relatively low-risk and low-operating cost solar projects than for larger, conventional energy systems.

IMPLICATIONS FOR U.S. POLICY

The preceding discussion should make it clear that energy-related issues can present major problems for foreign policy during the next few decades. Formulation of a coherent strategy for foreign policy cannot be made without assessing the potential effects of different plans for meeting U.S. domestic energy requirements, as well as plans for assisting other countries in developing new energy sources. Conversely, it is important that the foreign policy implications of energy policy enter the analysis of energy policy. Indeed, this is necessary simply in the interests of national security, since our security would clearly be eroded if energy-

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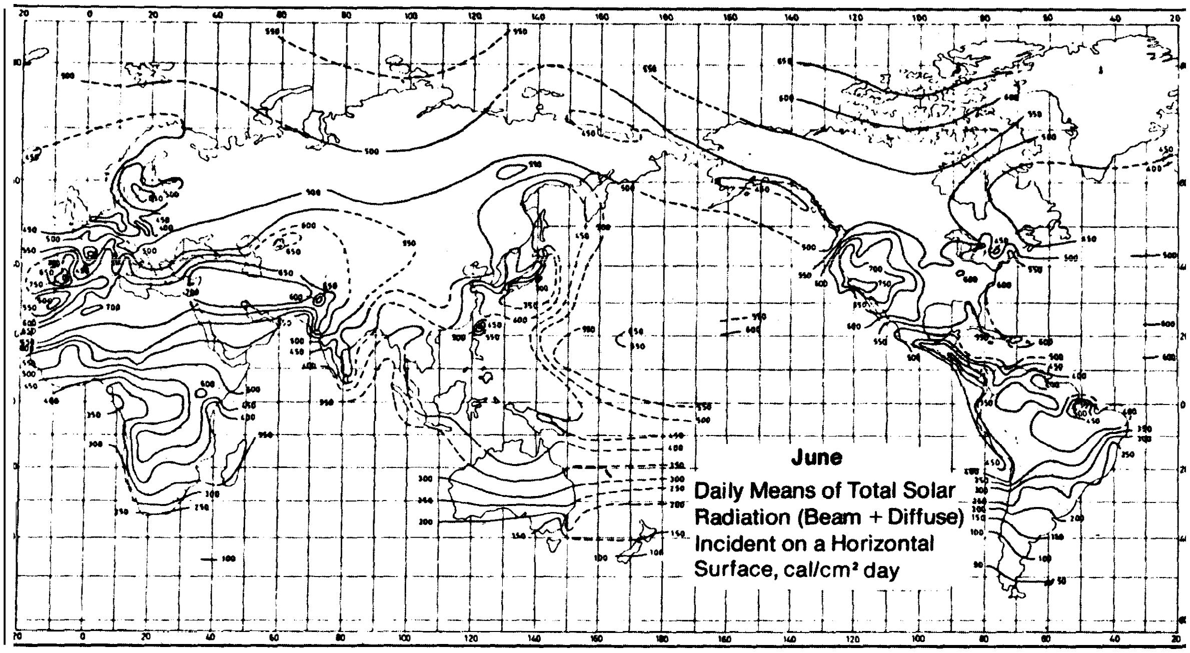
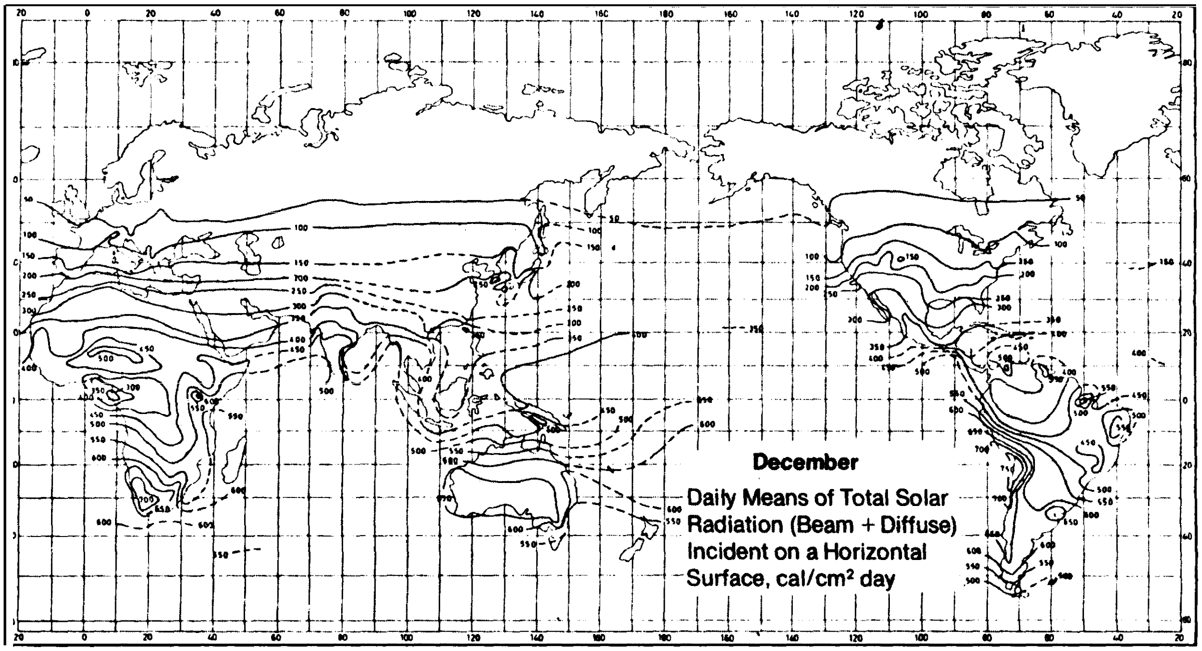
[5] *Photovoltaic Village Power Applications*, NASA-Lewis Research Center, June 30, 1977, p. 9.

[6] *Photovoltaic Refrigeration Applications*, NASA-Lewis Research Center, June 1, 1977, p. 28.

Figure VII-2– Worldwide Availability of Sunlight Resources



Daily Radiation for June



Daily Radiation for December

SOURCE John A Duffie and William A Beckman, *Solar Energy Thermal Processes,* John Wiley& Sons, New York, 1974, pp 35,37

Table VII-I. —Electricity Prices in Developing Nations

Electricity prices
(cents / k Whr)

Country	Capital city: Residence	Capital city: Commerce	Capital city: Industry	Urban, noncapital	Remote	Comments
Bureau: Asia						
Philippines .	1.6-4.7	2.2-4.7	2.8-3.2		3.8-16	Remote: Regional national grid, 3.8; Private small COOPS, 16
Pakistan . . .	2.2-2.5		2.2-4.2		.4-1.5	
Indonesia	7	10			.5	
Sri Lanka.	4-2					
Nepal	2-4					
Bangladesh.	1.1-1,9					Subsidized
India.	2.8					
Afghanistan	1.7-6.6					Different rates for Hydro, Diesel, Gas
Korea	4.6-11	5.6-7	3-4			
Thailand* . . .	.70-5					•BAHT/kWhr
Bureau: Near East						
Yemen	13.3					
Israel . . .	4.3		4.6-6.6			
Egypt	1.4-2.4			1-2.4	1.0	Subsidized (e. g., fuel 011 supplied at 1 /6 world price)
Syria	5					
Morocco . . .	5.5-13		12.5			
Portugal	3	4	4			
Sudan	8.6					
Bureau: Latin America						
Ecuador, ...	1.5-3.8					
Haiti	5.5-7.3				25/month for 25 watt bulb	
Colombia . . .	1-1.2			1-2.5	3-4	
Costa Rica .	4.4-5.3		4.7-6		4.4-4.7	
Guatemala .	4.4-6.4			3.2-7		Generation (58% thermal) 3.74, plan two hydro to reduce to 2.2. Local study shows small systems are not cost effective
Peru	1.9				1.9-3	
Guyana	19-21.9	29.9	27			Bauxite manufacturer gets subsidized rate of 10

Table Vll-1.—continued

Electricity prices
(cents/kWhr)

Country	Capital city: Residence	Capital city: Commerce	Capital city: Industry	Urban, noncapital	Remote	Comments
Dem. Rep. • .	2-6					● in RD ($RD?)
Brazil	5.6			6.9	3.7	plus 23% Fed. Tax
Nicaragua . . .	.87-11.3					should low residence be 8.7?
Panama	6-10					uniform in country
Uruguay.	4-5	2-3	2-3			uniform in country
Paraguay	5-8		6-8		6-8	
Chile*	.68-1			1.4		CH $
Bureau: Africa						
Benin	13	13	**13**	13		
Burundi	5	5	**5**	5		Two cities: one hydro, one (smaller) diesel. Plans for small hydro for 3 towns (GEIL)
Nigeria.	3-6	3-6	3-6	*4-7*		
Cameroon . . .	19	19	—	*23*		
Tanzania . . .	3-13	12-27	7-1o			Heavy Industry, 1-3
Liberia	6.5-8	6.5-8	5.5-7			Complicated billing
Niger	10-19	10-19				Average for Mission Residences, 12.5
Senegal	7-24	11-25		7-14		
Chad	14-26	14-26				Average for Embassy housing, 2
Kenya ., ...	2.8	11.2 -15.8	6-14.2			
Sierra Leone .	9	9	9			
Upper Volta.	16-26			16-26	8*	
Mauritania. . .	17					
Ethiopia.	5-7.5	5-7.5	5-1o	10-12		

SOURCE Agency for International Development response to telegram requests for Information Summer 1977

related tensions lead to conflict (even if we were not directly involved in the conflict), and it has already been eroded by our growing reliance on fragile supply routes for energy supplies critical to our economy.

Short of open warfare, competition over energy supplies could place a serious stress on traditional U.S. alliances and disrupt its attempts to improve relations with the Third World.

As the world's largest consumer and importer of energy and the acknowledged leader in most energy technologies, the United States will necessarily be the focus of international tensions generated by energy issues. Washington's relations with other industrialized countries (many of them U.S. allies) have already been strained by efforts to impose controls on nuclear exports and by a competitive scramble, following the 1973-74 embargo, to obtain reliable sources of oil imports. With the emergence of the United States as a major importer, petroleum has become a potentially serious source of division within the Atlantic Alliance, and with Japan. By contrast, Soviet capabilities to export oil and uranium have augmented the U.S.S.R.'s hold over its clients in Eastern Europe.

Its wealth and power have long made America the representative and symbol of the industrialized state in the eyes of less developed countries. Thus, inevitably, the Unitd States has been the focus of Third World resentment, a condition exacerbated by the scale of U.S. energy consumption in an increasingly shortage-conscious world and by recent American efforts to constrain nuclear exports.

A danger exists that energy problems may serve to reinflame some of the anxieties and ambitions which formerly dominated relations between the Communist and non-Communist nations. For example, there has been fear that the U.S.S.R. may successfully exploit the Arab-Israeli dispute to obtain influence over the disposition of Middle Eastern oil, upon which most of the industrialized countries of the world are so dependent. Rising energy costs, in conjunction with population, food, and resource pressures, may also frustrate the development hopes of many Third World countries, thereby strengthening the hand of Communist movements in those countries and consequently placing new strains on U. S.-Chinese relations,

Problems have also been created by the current administration's attempts to control the proliferation of nuclear weapons technology by discouraging non-nuclear weapons states from acquiring advanced nuclear energy equipment such as uranium enrichment and reprocessing systems. Efforts in this area have been rebuffed for a number of reasons, but two problems clearly are large factors:

- The failure of the United States to be able to offer any logical alternatives to the proposed nuclear development programs, and
- The implication that advanced nuclear systems are reserved for advanced nations, particularly those with nuclear weapons capabilities, while other nations are relegated to "second-choice" energy alternatives not seriously considered by the United States for its own use.

It is clear that accelerated development of solar energy and other renewable energy resources throughout the world will not be able to play a large role in the difficulties discussed here in the near future. But the development of a reliable energy source, applicable in a variety of countries, operating largely independence of foreign supplies of resources or technology, would certainly move things in the right direction.

Solar energy offers a particularly promising avenue for improving U.S. relations with the Third World — an area in which Washington has not been notably successful in recent years— because it is peculiarly adaptable to the needs of the developing countries. Solar energy is particularly attractive in this regard because it offers a means of directly contributing to improved well-being at the village level. Americans have not been adept at providing technology suited to the rural conditions, low-skill levels, and plentiful labor supplies which characterize the living conditions of much of the world's population.

Development of a set of solar energy systems which were genuinely useful to the Third World would provide an opportunity for the United States to demonstrate its concern for the aspirations of developing nations and to reinforce its global reputation for technological leadership and innovation.

The United States is in a position to assume leadership in the development of solar **energy resources** for a variety of reasons.

In the first place, the United States leads the world in solar energy technologies. The U.S. Federal budget in solar energy is probably larger than the combined solar budgets of the rest of the world. Soviet efforts in solar energy are virtually nonexistent.

Secondly, the United States is in a position to supply capital to developing nations either directly or through international lending institutions such as the World Bank or the Export-Import Bank.

Finally, a major U.S. commitment to the development of solar energy resources both for its own use and in its economic assistance policy, would have a subtle but powerful effect on the attitudes of other nations toward this technology.

FOREIGN TRADE IN SOLAR TECHNOLOGIES

BACKGROUND

If solar energy can, in fact, provide a competitive source of energy in many parts of the world, the potential for U.S. exporters should be substantial. There have not been any systematic surveys undertaken of the extent of this market, either by the U.S. Government or by U.S. solar industries. Some observers are convinced that there is a potential market of many hundreds of million dollars in annual sales to underdeveloped nations alone, and see no reason why the United States cannot capture a large fraction of that market.

Other analysts are more conservative. They note the limited capability of poor countries to finance imports, and the fact that much solar energy hardware is so simple as to be unprotectable by patent. Moreover, low labor costs in developing countries and the expense of transporting bulky solar equipment suggest that many less developed countries will find solar energy an ideal import-substitution Industry. I t is not difficult to imagine a nation like Singapore, which has quickly mastered a variety of medium-level technologies, developing the capabilities to fabricate some solar equipment. If this assessment is correct, the U.S. export market may be limited to relatively high technology solar components, e.g., solar cells, electrical controls, and heat engines.

More detail is available on photovoltaics than in other areas of solar technology. About 113 kW of photovoltaic devices were sold in non-Communist nations outside the United States in 1976 (a market of approximately $2 million) and a recent study has forecast that sales could reach about 88 MW ($44 million) by 1986.[7] This is still much too small to attract major industrial interest.

These projections will remain speculative until an overseas solar marketing survey is conducted to look at the energy needs of developing countries, the kinds of specialized solar technology that would be required to meet those needs, and the capability of the developing countries to pay for imports or to manufacture their own equipment, This information would be analyzed in the context of existing U.S. technology, and would indicate both how extensive the market for off-the-shelf solar hardware is, and how existing technology could be adapted to provide the specialized equipment needed by other countries.

The development of a foreign market would also substantially benefit the domestic solar energy equipment market, since the additional overseas demand for

[7] *Characterization of the Present Worldwide Photovoltaics Power Systems Market,* the BDM and Solarex Corporations (Draft report, May 1977).

solar facilities would result in larger production runs and more research, This should reduce domestic prices and accelerate improvements made in devices sold in the United States, yielding the United States a long-term advantage, even if developing nations began to produce their own systems in a decade or so It is likely that foreign manufacturers would sometimes require U.S. assistance, for example, utilize U.S., patents or licenses for solar devices,

Estimates of a large potential foreign market for solar energy are supported by recent studies conducted by the Department of State. One study, published in November 1976, indicated a substantial potential market for solar technologies in eight oil-producing nations [Algeria, Indonesia, Iran, Iraq, Mexico, Nigeria, Saudi Arabia, and Venezuela) The study showed that although al I eight countries preferred manufacturing solar equipment themselves rather than importing it, none was making a sufficient commitment to solar research to produce equipment which could compete with the small solar electric-generating equipment and desalinization processes being developed in the United States. State Department studies have also indicated that a smaller but significant market for solar devices exists in other oil-producing countries and in underdeveloped oil-importing nations, This last group of countries, according to surveys, was anxious to develop al I types of non petroleum energy sources and willing to devote a substantial amount of their capital if such sources have become economically and technically feasible. [a]

Some industrialized countries will develop their own solar energy industries and, as a result, will not constitute a significant market for U.S exports The exception may be certain high-technology components.

[a] Martin Prochnik, Office of Nuclear Energy and Energy Policies, Department of State, private communication, March 1977

FOREIGN COMPETITION IN SOLAR TECHNOLOGIES

Significant solar technologies have been developed in a number of other countries. Japan, Israel, and Australia produce more energy from the Sun each year than the United States, primarily because they have used simple hot-water and space-heating devices for decades France, Germany, Japan, and perhaps Israel sell more solar equipment abroad annually than the United states

There are several reasons for this. First, conventional energy in the United States has been, for the most part, plentiful and inexpensive; consequently, this Nation has delayed emphasis on solar heating and hot water (except in Florida and southern California during the 1940's and 1950's) while countries such as Japan, Israel, and Australia have been installing such devices for decades, Second, the United States spends proportionately more for research than other countries with solar budgets, most of which stress currently marketable technologies. Private industry in most other countries has been more deeply involved in solar technology than has its U.S. counterpart, and it is private industry, not the Government, that usually determines an export market. Finally, the United States spreads its financial resources among a broad range of solar technologies; many other countries stress funding of fewer specialized projects, which leads to more rapid marketing of results.

[n the past year, France has doubled its solar budget to almost $10 million per year, putting special emphasis on developing 300 kW, 800 kW, and 3.5 MW solar electric systems. West Germany, which spends about $6 million per year, also increased its funding for solar energy substantially Japan is spending about $5 million per year in its government-sponsored Project Sunshine. Israel has boosted its solar commitment to about $2 million. Iran has extended its solar program, opening a 100-person solar institute, Saudi Arabia has created a similar center, although smaller, staffed by about 20 technologists. The Common Market has decided to build a 1 MW central thermal power station, probably in Italy, and Spain is in the process of locating a site for a solar research institute with help from the United States and several European countries.

THE IMPACT OF SOLAR ENERGY ON AMERICAN LABOR

Onsite solar technology appears to be more labor-intensive than contemporary techniques for supplying energy; thus, in the short term, the introduction of solar energy devices might create jobs in trades now suffering from serious unemployment. In general, the new jobs will be distributed widely across the country and will not require laborers to live in remote or temporary construction sites because most workers should be able to find jobs in areas close to their homes. Work on solar equipment, for the most part, should necessitate only simple retraining programs, although there may be shortages both of engineers and architects qualified to design solar equipment, and of operators trained in maintenance of some of the larger and more sophisticated solar devices which have been proposed.

Assessing the long-term implication of technological development on the work force, however, cannot be reliably undertaken with contemporary economic methods. Long-term labor impacts will depend on forecasts of future growth rates both in the economy and in U.S. energy consumption — subjects about which there is great confusion and disagreement. Although making economic projections is hampered by imprecise methodology, it is possible at this point to outline some of the critical issues which concern the effects of solar energy development on labor.

MANPOWER REQUIREMENTS

One of the most critical issues in evaluating the impact of a new energy technology on labor, and one of the most difficult to deal with reliably, is how the technology will affect overall manpower requirements in the energy industry. Tables VI I-2 and VI I-3 compare the manpower requirements of a conventional coal-fired generating system with the manpower required to construct and to operate each of two kinds of solar devices capable of producing equivalent amounts of energy. Only first order effects have been considered, and the estimates made about solar devices are necessarily speculative. One overall conclusion seems inescapable, however: a large fraction of the value of solar equipment is attributable to direct labor costs.

The high labor intensity of solar equipment is not surprising, Most devices can be constructed from relatively inexpensive material, and the small equipment examined here would not require extensive capital-carrying charges during construction. Factories for mass production of photovoltaic devices, heat engines, and other components of solar technologies will probably employ sophisticated and expensive equipment which will reduce labor in these industries, Much of the work of installing solar equipment will continue to require direct onsite labor.

Table VI I-2 lists all labor requirements for construction at the plant site, to build the 800 MWe turbine generator in a factory, to operate the generating facility at an average of 60 per-cent of full capacity for a period of 30 years, to build and operate a coal mine large enough to support the plant, to transport the 2.5 million tons of coal per year needed to operate the plant, and to construct and maintain a transmission and

Table VII-2. —Labor Requirements for a Conventional 800 MWe Coal Plant (in units of man hours per megawatt year)

	Construction	Operating and maintenance	Total
800 MWe coal plant. ...	330	380	710
coal strip mine using western coal . . .	20	360	380
coal preparation plant.	3	290	293
coal transportation	—	340	340
electric transmission	40	5	45
electrlc dlstribut!on	190	310	500
steel & concrete production	10		10
turbine/generator manufacturing. . .	170	0	170
Total	763	1685	2348

Assumptions:
— 800 MWe coal plant operating at 60 percent peak capacitv for 30 years:
— western' coal' strip mine with 525-mile train line;
— all data based on Bechtel data with the exception of the turbine generator manufacture. It was assumed that the turbine/generator cost of $150/kW of which 25 percent was labor and that this labor was paid at an average rate of $10/hr;
— calculations divide the sum of construction manpower and 30 year operating manpower requirements by the total number of megawatt years of energy produced by the plant.

distribution network. It is noteworthy that the operating and maintenance labor is more than twice as great as the labor needed to construct the facilities, and that nearly 20 percent of the manpower rquirements in operations are used to maintain the distribution facility.

Table VII-3 presents an estimate of the labor required to build and maintain a flat-plate solar water heating system and a small tracking photovoltaic system in Albuquerque, N. Mex. The hot water system requires 1.5 to 2.5 times more labor than the conventional coal-fired generating facility and even more if the utility must maintain a substantial facility for providing backup power. The range shown for the solar devices reflects the range of labor requirements provided by collector manufacturers contacted. It is probable that the labor requirements of a mature solar industry will be close to the lower end of the range shown.

The major source of error in these estimates, apart from inaccuracies in data gathering, is the failure to consider the many secondary kinds of employment which could be created by both solar and conventional facilities. A significant fraction of this secondary labor would come in the manufacture of primary metals, glass, etc., for both solar and conventional systems. Given that the weight of solar devices would be equal to, or more than, the weight of conventional systems per unit output, it seems unlikely

Table VII-3. — Labor Requirements of Two Types of Distributed Solar Energy Systems (in man hours per megawatt year)

	Construction	Operating & maintenance	Total
1. Solar hot water heaters (8 m^2 flat plate) .,			
— manufacture collector	800-2500	0	800-2500
—install collector.	1200	0	1200
—routine O&M	—	1200	1200
Total for hot water system •	2000-3700	1200	3200-4900
Total for hot water system including backup	2340-4040	—	3540-5240
II. Tracking silicon photovoltalc system:			
a. Electrlc only (50 m^2)			
— manufacture collector and cells	2600-3300	—	2600-3300
— install collector.	1800-4600	—	1800-4600
—operate system.	·	6800	6800
Total for tracking photo-voltaic system	4400-7900	6800	11200-14700
Total for tracking photo-voltaic system including backup	4740-8240	—	11540-15040
b. Electric + 0.29-Thermal (Including backup).	2240-3740	3000	5240-6740
c. Electric + Thermal (Including backup).	1130-1750	1240	2370-2990

Assumptions:
- — 20 year system life;
- — installation includes 75 feet of piping costing 0.11 MH/ft to Install;
- — flat **plates installed** for 1.3 MH/m and tracking collector installed for 1.3-3.33 MH/m^2;
- — cells assumed to be 18 percent efficient, optical efficiency 80 percent.
- — labor for providing backup power is assumed to be 50% of the construction labor shown in table VII-2— (e. g., 340 man-hours/ MW-year)
- — flat plates assumed to provide 930 kWh/m^2-yr (Albuquerque);

  cells provide 320 kWh/m^2-yr electric and 1450 kWh/m^2-yr thermal for PV system (Albuquerque);

  O&M labor for PV system assumed to be 0.25 hrs/m^2-yr (see table XI-7);
- — flat plate manufacturing labor based on data from several collector manufacturers;
- — concentrator manufacturing labor assumed to be .024 MH/lb of collector for PV concentrator given in table VII-7 (with concrete and **sand excluded) with the labor to produce the raw materials added;**

  .024 MH/lb is approximate labor Input for automobile manufacturing based on employment and production for 1973 given in 1976 *Sfatisfica/ Abstract of the United States,* U.S. Dept. of Commerce, Bureau of the Census, pp. **369, 791.**

that the differences in labor requirements illustrated above would be eliminated by a more detailed analysis.

Some collector designs (e. g., plastic collectors) will almost certainly require less manufacturing labor but they will probably require more maintenance labor, while other designs which require less material (e.g., tubular designs) may require more manufacturing labor than simple flat-plate systems.

The photovoltaic system shown in table VII-3 requires more labor when only electricity is produced, because the output is about one-third that of the hot water system. The larger operating labor results from the greater complexity of the tracking system. If the system provides thermal output as well, labor input per unit of combined output would be about one-third lower than for the hot water system.

The labor requirements per unit of solar energy delivered would be higher in areas of the country which do not receive as much sunshine as Albuquerque since each unit area of collector would produce less output.

It should also be noted that onsite systems which rely on utility systems for backup would probably not reduce the labor requirements for transmission and distribution systems significantly. This is important since a large fraction of the labor required by conventional utilities is due to these energy distribution systems. A shift toward decentralized solar energy systems could, therefore result in replacing centralized facilities with solar units requiring greater amounts of labor while leaving the labor-intensive distribution systems intact.

SOME QUALITATIVE IMPACTS

While the analysis of the overall labor requirements of solar energy is very primitive, it is possible to be somewhat more confident about some qualitative aspects of solar energy's impact on the work force.

Geographic Distribution

Employment in installation and operation of solar equipment can be expected to be distributed over a large part of the country. Initial installations of solar equipment are likely to occur in places with high insolation — the South and Southwest, Locations with relatively low levels of sunlight, such as the Northeast, however, tend to have high energy prices, Thus, while low insolation levels make solar energy in the North expensive, competing energy sources are also expensive, so the net economic competitiveness of solar devices may be as high in the North as in more favorable climates, Employment in installing solar energy is, therefore, likely to be as geographically dispersed as the building industry.

One thing about solar employment seems clear— none of the small solar devices considered in this report will require the major dislocation of a work force, or the establishment of temporary work camps as may be required for construction of a pipeline, an offshore drilling operation, or a large central generating facility in a remote location. The relatively small solar devices analyzed here will provide employment in close proximity to where workers presently live, and therefore will avoid the social disruptions associated with large influxes of temporary workers.

Unlike most major manufacturing facilities, solar manufacturing at present is spread across the country in literally hundreds of small companies. The future of these businesses, however, is very uncertain. If the demand for solar equipment increases substantially, the field may be dominated by a small number of large manufacturing firms, much as the manufacturing of conventional heating and cooling equipment is dominated by a small number of firms.

On the other hand, solar devices may be designed for special climates and sufficiently site-specific for manufacturing to remain geographically dispersed, much as facilities for manufacturing modular homes are today. It seems clear that because of the sophisticated technology employed, the manufacturing of components such as photovoltaic devices, heat engines, and concentrating devices will occur in a relatively small number of facilities.

Stability of Labor Demand Associated With Solar Equipment

If a major demand develops for solar energy, it is likely that employment in the area will be as stable as work in any typical building trade; the solar equipment will simply add jobs at each construction site. If a major retrofit market develops, there could also be major employment opportunities in this area; maintenance of solar equipment will also provide a stable source of jobs.

Skill Levels Required

Most of the employment directly created by a shift to solar energy will be in installation of the equipment by the conventional building trades, and in the creation of new manufacturing industries. The skills required for installation of the equipment will be very similar to those required for conventional construction projects, although some brief training programs will undoubtedly be desirable to familiarize workers with the new equipment and its installation. Most of the work will be in framing roofs, laying footings, plumbing collectors and storage tanks, excavating trenches and pits for pipe-runs and storage tanks, installing sheet metal ducting, insulating pipes and tanks, and installing electronic control units. The work will be nearly identical to the installation of sophisticated air-conditioning and heating systems in conventional buildings.

Larger solar installations, such as those serving groups of buildings and large industrial operations, are likely to require supervisors, managers, draftsmen, designers, and engineers in roughly the same proportion as these skills are required in the construction of conventional power-generating facilities. In fact, since many large onsite solar facilities are likely to be supplemental to conventional boilers and generators, the solar equipment would simply add work in these areas at each installation, There may be a shortage of engineers with adequate knowledge in areas critical to onsite power in general and solar devices in particular,

Designing a reliable and efficient onsite device for a large installation (such as an apartment or industry) requires experience with other types of equipment not now conventionally used in utilities or building energy systems. Solar onsite systems require even more expertise in order to manage the added complexities of collector design, thermal storage systems, more elaborate control systems, possibly of batteries, heat engines, and photovoltaic devices

Employment opportunities in manufacturing are more difficult to define, since the pattern of growth in the industry is presently unpredictable. Work opportunities will include glazing, metal extrusion, component assembly, and chemical processing (for photoelectric devices, selective surface formation, storage systems, etc.). It is difficult to anticipate whether the employment will be created in a large number of dispersed fabricating facilities, in large central plants, or in both.

The skills required to maintain the type of simple solar equipment installed on homes and small apartments will be similar to those required for conventional appliance maintenance of utility gas and electric power equipment. Most of the personnel in these professions will require additional specialized training in solar technology. There is a serious shortage of persons with the skills needed to operate intermediate-sized solar or conventional onsite energy equipment. Owners of small total energy systems report difficulty in finding and holding persons trained in operation and maintenance of engines and heat recovery units, energy control switching, and other associated equipment. Maintenance of a sophisticated collector system will present similar problems. Many now employed in the operation of total energy systems learned the requisite skills from the U.S.

military services. Such training appears difficult to obtain in private industry.

Tables VI I-4 and VI I-5 demonstrate jobs which must now be done to support conventional electric generating equipment. The impact of solar equipment on jobs will depend on the extent to which solar devices displace fuel consumption (replacing jobs in mining with jobs in solar technologies), the extent to which the technology would cut the demand for peak generating capacity (replacing jobs in constructing and maintaining generating equipment with jobs in solar technologies), and the extent to which the need for transmission and distribution equipment would be reduced.

These effects are listed in the order of their likelihood. It is most probable that solar technology would initially affect only fuel utilization, and would affect transmission and distribution requirements only in an extreme case where all or much of local energy needs are met with solar equipment It should not be assumed that an increase in solar utilization would necessarily replace any of the employment indicated in tables VI I-4 and VI I-5, The expected increase in U.S. and worldwide coal demand is likely to be so large that employment in mining would be unaffected by an expected penetration of solar energy into the market, Several observations can be made on the basis of the tables, however:

- Small solar installations are likely to employ more blue collar workers than

Table VII-4.—Skills Required for Constructing a Coal-Fired Electric Generating Plant and Operating the System Over a 30-Year Period

1. Skills Required for Plant Construction (as a percentage of the 3,576 man-years required to construct the plant and the transmission and distribution network)

	Coal-Fired Electric Generating Plant	Transmission and Distribution Facilities	Total
Non-manual construction work . .	9% (63°/0 engineers and 25% draftsmen and designers)	13% 25% draftsmen and designers)	22%
Manual construction work .	49% (variety of trades)	29% (mostly electricians)	760/0
Total construction work . . .,	58%	42%	100%

II. Skills Required to Operate and Maintain Equipment for a 30 year Interval (as a percentage of the 10,893 man-years required)

	Coal Mining and Coal Transport	Coal-Fired Generating Plant	Transmission and Distribution Facilities	Total
Non-manual operating work	17% (mostly trainmen)	6% (67% supervisors and managers)	3% (mostly supervisors working on distribution system)	26%
Manual operating work	42% (mostly miners and trainmen)	16% (variety of trades)	15% (mostly electricians and meter readers for distribution system)	73%
Total operating employment	59%	22%	18%	100%

•Details about assumptions used shown in Table VII-5.

SOURCE: Based on data in "Manpower, Materials, and Capital Costs for Energy-Related Facilities," Bechtel Corporation, April 1976.

Table VI I-5.— Detailed Breakdown of Skills Required for Conventional Electric System*
(man-years per 800 MW_e coal-fired plant and associated distribution and fuel facilities)

	Western strip mine & coal crushing & sizing plant (annual operations)	Coal transport unit train (annual operations)	Coal-Fired Elastic Generating Plant (800 MW) Annual Operations	Coal-Fired Elastic Generating Plant (800 MW) Construction	Electric transmission (200 miles in length-national average) Annual Operations	Electric transmission Construction	Electric distribution Annual Operations	Electric distribution Construction	30 years of operations	Construction	Total construction & 30 years operation
Non-manual workers											
1. Engineers—conductor		37							1110		1110
—civil				93	.02	12	1	81	31	186	217
—electrical	.2		4	68	08	25	3	161	218	254	472
—mechanical	.2		2	52	02	4		27	67	83	150
—mining	1.1								33		33
—industrial	.2								6		6
—safety	.2								6		6
—environmental	.1								3		3
Total engineers	2.0	37	6	213	.12	41	4	269	1474	523	1997
2. Designers and draftsmen	1		1	85		17		109	60	211	271
3. Supervisors and managers	14		14	40	.23	3	8	18	1087	61	1148
4. Other	8								240		240
Total nonmanual labor	25	37	21	338	.35	61	12	396	2861	795	3656
Manual workers											
1. pipefitters			8	400					240	400	640
2. pipefitter/welder			12	180			3		450	180	630
3. electrician	11		12	280	.36	133	36	843	1781	1256	3037
4. boilermaker			8	300					240	300	540
5. boilermaker/welder				100						100	100
6. iron worker				141		44				185	185
7. carpenter				140						140	140
8. equipment operators	36		20	100					1680	100	1780
9. other	68	37		120	.37		16		3641	120	3761
Total manual labor	115	37	60	1761	.73	177	55	843	8032	2781	10813
TOTAL LABOR	140	74	81	2099	1.08	238	67	1239	10893	3576	14469

* Based on Information in *Manpower, Mater/a/s and Capital Costs /or Energy Related Facilities*, John K Hogle, et al , Bechtel Corp for Brookhaven National Laboratory Associated Universities, Inc , Contract No 354617S, April 1976

professional employees. Solar installations on individual buildings typically require one supervisor for each 10 workmen, [9] while the ratio for the conventional coal equipment shown in table VI I-4 is closer to 1 to 3, The larger industrial and community solar systems would, however, require much more professional work.

- Nearly 50 percent of the jobs associated with operating and maintaining conventional equipment is associated with coal mining and transporta-

[9] FEA *Project Independence* Task Force Labor Report

tion. Jobs in these sectors could be replaced with jobs in repair and maintenance of onsite equipment.

- About 40 percent of the work required to build a conventional electric system and *30* percent of the work required to maintain it is associated with distribution equipment, which is unlikely to be affected by solar technology.

Working Conditions

Expansion of the solar energy industry should not raise serious health or occupational hazards, but some of the possible problems are discussed below. The manufacture of some photovoltaic devices employs cadmium and arsenic compounds which could present hazards to workers assembling these units. Manufacture of plexiglass and other plastics used in photovoltaic devices can also involve handling potentially harmful chemicals. These manufacturing hazards are not unique, however, because these compounds are widely used in other industries. Some steam-fitting jobs will involve high-pressure steam lines, and some proposed thermal storage methods will require very hot oils, possibly explosive or toxic. These issues deserve serious attention before such installations become common place. Devices using hazardous material may only be employed in larger, more centralized solar facilities and are unlikely to be found in onsite residential systems. Replacing jobs in coal mining for those in *solar* equipment maintenance, however, would probably result in overall improved working conditions.

Organized Labor

organized labor is enthusiastic about solar energy's potential for creating jobs. Like many other construction trade unions, the sheet metal workers (SMWIA) have been hard hit by unemployment: the SMWIA has a national unemployment rate of 30 percent to 35 percent, with unemployment reaching 50 percent to 60 percent in some areas of the North and Northeast “) These are regions where energy prices have risen very rapidly in recent years. I t is possible that sizable near-term markets for solar equipment can be found in these areas in spite of their re atively unfavorable climates.

I n 1970, the plumbers and pipefitters had a nationwide unemployment rate similar to that of the sheet metal workers. A potential labor problem associated with implementation of solar technology is the question of which union will subsume the categories of newly created jobs. Until recently there have been few solar installations so that few u n ions have staked out terri toritorial prerogatives. For the most part, the solar energy field is still wide open to jurisdictional competition. The situation can be expected to change as more work in the area becomes available. An arrangement has already been negotiated between the Sheet Metal Workers and the United Association of Plumbers and Pipefitters which calls for joint crews in the installation of hot air collectors using liquid storage systems, Jurisdictional disputes could be a serious problem in other areas, however, unless al I issues can be settled as amicably as this one has apparently been.

Generally, union officials feel that an upsurge of solar construction and installation would radically alter the number, not the types of jobs available to union members. Firms that now produce heating, ventilating, and air-conditioning equipment— many of them already active in solar collector construction — would simply expand their operations. Any new firms established would be unionized in conventional ways.

While labor has occasionally resisted the introduction of new technologies into the building industry, this resistance has always been directed at technologies which reduce jobs on each building site or which transferred employment from one building trade to another. The disputes associated with the

“” B.McMonigle, SMWIA, private communication, 1977 introduction of plastic plumbing, prehung doors, and metal studs all resulted from one of these effects. Solar equipment would add work at each site without displacing work in other areas, It is, therefore, difficult to imagine any group with a motive to resist its entry into the market.

LONG-TERM IMPACTS

The overall impact of generating a substantial fraction of U.S. energy from small solar devices is hard to assess, since current economic theory has no satisfactory method for such analysis. None of the major price equilibrium models used to determine the future of U.S. energy supply and demand adequately treat employment issues; most make the overwhelmingly simple assumption that there will be full employment during the entire period analyzed. As a result, many of these models tend to ignore the influence of alternative energy strategies on unemployment, The difficulties of predicting economic impacts are magnified by the lack of information necessary to translate a workable theory or model into useful policy.

In the absence of an adequate methodology, the most critical questions involving the impact of solar technologies on the work force cannot be answered with certainty. An example of one difficulty can be seen in the problems associated with interpreting the implications of labor intensity. If rapid rates of growth are expected in both the U.S. economy in general and the energy production sector in particular, and if unemployment is expected to be very low as a result, any shift to a labor-intensive technology like solar energy could prevent wages from keeping pace with growth in other sections of the economy, An industry with high labor intensity requires more manpower for the same output than industries with low labor intensity. As a result, the average wage paid per worker must be lower for the labor-intensive process. If growth is not expected to be sufficient to eliminate unemployment, labor-intensive industries will be beneficial to both labor and society by productively employing a larger fraction of the work force.

Other questions which must be addressed include:

1. To what extent would the energy produced by solar equipment displace imports, nuclear, or indigenous fuel supplies? To what extent will solar energy fulfill energy needs that might not otherwise be met? (If solar energy filled such needs, employment could grow in areas of the economy not otherwise possIble.)
2. To what extent will solar energy sources be able to reduce the need for installing additional electric generating facilities as well as reduce the demand for fuel?
3. If imports are reduced, and funds invested instead in U, S. solar industries, how much direct and indirect employment would be created? How much would employment be reduced in industries now benefiting from the export market stimulated by our purchase of foreign fuels?
4. What kinds of growth rates can be expected in energy sources other than solar energy? WiII this growth rate be constrained by a shortage of capital, resources, and demand, or by a shortage of critical skills? Would solar energy compete directly for scarce resources or would it be able to tap other capital or labor supplies?
5. What kind of work force dislocations could be expected in a shift from one energy source to another? Would new skills not now available **in the building trades be demanded? What kinds of transient unemployment** could be expected?

NET ENERGY USE OF SOLAR EQUIPMENT

Clearly solar energy devices cannot provide a useful contribution to the world's energy problems if more energy is used to construct the devices than can be extracted usefully from them. A brief examination of this question indicates that solar equipment can clearly be a net producer of energy. Unfortunately, no straightforward methodology has been developed for computing the total amount of energy consumed in manufacturing, installing, and operating a piece of mechanical equipment. Two different techniques will be used here: 1) computing the primary energy required to manufacture the materials used in the solar collectors and conversion devices, and 2) computing the energy used by assuming that the energy used per unit investment in solar equipment is the same as the national average energy use per unit of investment. The results of both approaches are shown in table VI I-6

PRIMARY ENERGY REQUIREMENTS

The amounts of different types of materials required to construct five representative onsite solar energy systems are illustrated in table VII-7 and the estimated energy content of these materials is shown in table VII-8. (It is assumed that energy consumed in manufacture, installation, and transportation of collectors is relatively small.) The largest uncertainty shown in these tables is the energy required to manufacture silicon. The larger estimate of the energy content of silicon reflects the technology of manufacturing silicon and fabricating silicon which was used in mid-1975. Recent improvements in manufacturing techniques have reduced the energy required in this process and further reductions are expected using techniques now in development (see chapter X). The lower figure shown in the table assumes that silicon is manufactured using an advanced technique in which energy conservation has been carefully considered.

Energy requirements of silicon cells could probably be reduced below the lowest number shown in the table if a technique is developed for manufacturing thin cells from amorphous silicon material. The amorphous cells may require as little as 1 percent of the silicon required in contemporary cells. Silicon cells now require an energy consuming crystal growing process and the resulting crystals must be sliced into wafers. Both processes waste a considerable amount of silicon,

It should also be possible to reduce the amount of energy required in the manufacture of many other of the products shown in table VI I-8 if close attention is paid to energy conservation. The energy content of U.S. steel, for example, has declined by 25 percent since 1947, and the Germans use about 68 percent as much energy as the United States uses to manufacture stee].11 The Aluminum Company of America (ALCOA) has apparently developed a smelting process capable of nearly halving the energy used to manufacture alum inure. [2]It can be seen from table VI 1-6, however, that acceptable "energy-payback" times can be achieved even if the materials are manufactured using 1970 U.S. technology.

It must be remembered that the energy content of the solar devices shown does not include any of the energy required in factories which assemble the collectors, the trucks which deliver the materials to the factory and the collectors to the installation site, the food consumed by installation workers, or a number of other "secondary" sources of consumption,

" M H Ross and R H Williams, *Energy and Economic Growth*, printed by the Joint E conomic Committee in Achieving the Goals of the Employment Act of 1946— Thirteenth Anniversary Review, Volume 2, Energy Paper No 2, Aug 31,1971 (91-592), p 7

[12] J G Meyers, et al , *Energy Consumption in Manufacturing*, report prepared by the Conference Board for the Energy Policy Project of the Ford Foundation, Ball inger, Cambridge, Mass , 1974

Table VI I-6 .—Energy Payback Relations for Onsite Solar Conversion Systems in Albuquerque

(See Tables VI I-7 & 8 for Assumptions)

	Stirling engine in tracking dish	Concentrating photovoltaic system (100x)	Flat plate photovoltaic array	Flat plate thermal collector	Pond thermal collector
1. energy required to manufacture one square meter of collecting system (kWh/m2	450	425*-525	301●-8844	185-320	16-250
2. energy produced by the s stem annually (kWh/m²/year)					
—thermal	1050	1440	—	930	400-800
—electrical + ... (primary energy) equivalent)	2069	1100	1000	—	—
3. payback time computed from (1) and (2) above (in months)					
—payback from thermal energy	5.1	4.4 (3.5)*	—	2.4-4.1	0.5-3.8
—payback from electric energy	2.6	5.7 (4.6)*	106 (3.6)*	—	—
—payback from total energy	1.7	2.5 (2.0)'		2.4-4.1	0.5-3.8
4. allowed cost of system (in $/m²) for a 1-year energy payback time assuming that solar devices use the same energy input per dollar of initial cost as the U.S. average of new investments					
—thermal	88	120		77	33-66
—electrical	172	291	83 (700$/kW)	o	—
—total	260	411	83	77	33-66

•Assumes advanced manufacturing techniques.
+ Average efficiency of electric generation and transmission distribution assumed to be 290/..

NOTES: It is assumed that the engine used is 32% efficient and that the optical systems in the concentrators are 80% efficient Flat-plate silicon cell arrays are assumed to be 12% efficient and concentrator cells are 20% efficient (See volume II, chapter IV for detailed assumptions)

ENERGY USE PER DOLLAR OF GNP

One technique for counting all of the energy which might enter a solar energy system from secondary sources is to examine the average consumption of energy in the United States per unit of GNP. [3] An examination of the incremental change in energy consumption per incremental change in GNP over the past 20 years shows that in the United States about 12 kWh were consumed for each added dollar of GNP. The average kWh consumed per dollar of GNP has averaged 9-10 during the past few years. (All quantities in 1976 dollars.) The link between GNP and energy consumption is the

[11] Technique suggested by Dr R D Huntoon, President, MEMO, Silver Spring, Md.

Table VII-7.– Materials Required in Solar Energy Devices (kg/m²)

	Concentrator + stirling engine	Concentrator + silicon photovoltaic	Flat plate silicon photovoltaic	Flat plate (thermal only)	Pond (thermal) only
Steel . . .	30	27	0-3	4-8	0
Glass . . .	16	16	6	6-12	0
Concrete	79	79	0	0	0-40
Sand	115	115	0	0	0
Polyurethane	0.3	0.3	0	0	0.6-6
Copper	0.4	0.4	0	4-8	0
Silicon cells .	0	0.0024 '-0.007	0.24 '-0.71	0	0

"Using advanced manufacturing techniques (not using amorphous silicon)

Energy Content

SOURCES Concentrator data from Hildebrandt, A F , and L. L Vant-Hull, "Power with Heliostat s," Science 197 (1977). p 1139

Silicon data from L P Hunt (Dow Corning Corp) Total Energy Use in the Production of Silicon Solar Cells from Raw Materials to Finished Product *The Conference Record of the 12th IEEE Photovoltaic Specialists Conference*— 7976 Baton Rouge La November 1976 p 349

Other CO l lector data from man ufacturers

Table VII-8.— Primary Energy Required to Produce Component Materials for Solar and Conventional Power Systems

	Total energy require-ment (kWh/kg)	Source of input Energy (in percent)				
		Coal	Oil	Gas	Electricity	Fuel byproducts
Polyvinyl chloride resin, .	22	9.1	19.4	55,6	23,4	(7.5)
Portland cement —wet process	2.1	30.4	13.7	39.9	16.0	—
—dry process. . .	**1.9**	**42.6**	**8.0**	**32.4**	**17.0**	—
Copper	30	10.1	13.5	38.4	38.0	—
Steel ... .,	5.1	81.1	6.6	13.5	8.4	(9.6)
Glass containers . .	4.8	35.8	7.3	48.8	14.5	(6.4)
Silicon	12400-1050	–	–	–	~100	—

SOURCES The Data Base The Potential for Energy Conversion in Nine Selected Industries, FEA, June 1974, p 20

Silicon data from Hunt, L P

subject of consider-able contention [4] but it is c l ear that the ratio is to some extent the function of the society West Germany and Sweden, for example, consume about two-thirds as much energy per unit of GNP as does the United States, although an exam i nation of recent Swedish data seems to indicate that since the late 1960's the incremental amount of energy consumption per incremental amount of GNP in that country has been close to that of the United States. The statistics cited in the previous

[4] See Ross and Williams, op. cit

section at least indicate that it is possible to shift energy consumption from the manufacture of primary materials to other areas of the economy—areas where energy consumption per unit of value may not be as great.

The allowable cost for solar energy systems capable of "paying back" the energy invested in them in one year (assuming the current U.S. ratio of incremental energy to incremental GNP) is shown in table VI i-6.

Since the allowed costs computed in this may correspond to costs which can probably be achieved with solar devices, the results of this method are roughly consistent with the previous method; both indicating that net energy should not present a barrier to the use of solar energy. (It should be noticed that if it is assumed that solar manufacturing is more energy intensive than an average process in the economy by some ratio *R.* then a solar system with a cost equal to the allowed cost shown in the table would require *R* years to pay back the energy it contain s.)

THE IMPACT OF ONSITE ENERGY ON THE ENVIRONMENT

While solar energy equipment is not free of adverse environmental effects, providing energy from sunlight will have a much smaller environmental impact than conventional sources providing equivalent amounts of energy. The primary environmental effect of utilizing onsite solar energy will be reduction of the potential adverse environmental effects associated with other energy sources.

The negative environmental effects of solar energy devices stem primarily from two **sources: (1) land use requirements, which could compete with other, more attractive uses of land, especially near populated areas, and (2) emissions associated with the mining and manufacture of the materials** used to manufacture solar equipment (manufactured steel, glass, alum inure, etc.). In general, solar devices manufactured using conventional energy sources, create more pollutants while they are being manufactured than an equivalent conventional plant (primarily because solar equipment requires a greater capital investment per unit of output) but this assymetry is outweighed by the fact that the solar devices produce much less pollution during their operational lifetimes. The net emissions associated with solar devices are much smaller than those of conventional fuel-burning plants.

Solar energy devices can change the amount of energy absorbed by the Earth's surface, and could have some small effect on the local thermal balance. The effect, however, would typically be no greater than the change in local climate produced by covering land with equivalent areas of highways, buildings, or parking lots.

In addition to these primary effects, a number of the specific storage and energy conversion systems discussed in other sections of this study wouldl have adverse environmental effects because of noise, local heat and other minor emissions, and use of toxic chemicals. These effects are discussed in the chapers about individual technologies.

DIRECT ENVIRONMENTAL EFFECTS

Emissions Associated With Operating Energy Equipment

The primary direct impact of solar energy on the local environment will be the elimination of adverse environmental effects attributable to the burning of conventional fossil fuels. The damage done to the environment by conventional energy sources is well known, although the magnitude of the long-term health and climatic effects is still being determined. The large number of ways in which producing electric energy from a coal-f i red steam plant, for example, can adversely affect the environment are suggested below:

- Strip mining required to harvest the coal resources can permanently change local topgraphy, alter stream beds, disrupt or contaminate ground water, and produce large amounts of rubble, noise, and dust in mining areas. Reclamation can be difficult, particularly in areas where water shortages exist. Underground mines have fewer external effects, but can create safety and health problems for miners
- Processing the coal can produce large amounts of solid waste and cause toxic chemicals to be released into local water.
- Transporting coal can require the use of trains which burn oil or use electricity from some fossil source In some cases new rail lines will be required.
- **Burning coal produces large amounts of airborne particulates, sulphur and** nirogen compounds, hydrocarbons, carbon monoxide, and a variety of other air contaminants In addition, large amounts of solid waste are produced either as coal ash or as byproducts of removing chemicals from the smokestacks of the plants
- Once generated, the electricity must be transported along extensive networks of transmission and distribution lines which require the clearing of long strips of land

Several recent studies have also indicated that continued large-scale consumption of fossil fuels could release so much carbon dioxide into the atmosphere that the gas would create all green house" effect, raising the average temperature of the Earth's atmosphere by as much as 6 "C (11 "F) in 100 to 200 years.[15] The impact of such a climate change on agricultural production and the polar caps is difficult to predict. In addition, the effect of using solar energy to replace gas, oil, or wood home space and water heating would be to reduce the thermal and chemical pollution associated with these means.

Negative environmental effects can also be expected from other conventional approaches to electric generators. Electricity provided from nuclear fission devices would avoid many of the environmental impacts associated with the consumption of coal, but the nuclear process produces thermal pollution and radioactive wastes with long lifetimes. Hydroelectric facilities eliminate most of the negative impacts of other electric sources, but can have a major impact on land use because of the need to flood land areas. Natural gas has fewer adverse environmental impacts, but reserves are drastically depleted,

A comprehensive description of all environmental impacts of conventional energy sources is beyond the scope of the present study, but a brief comparison of the impact on air and water quality by solar and conventional energy sources is shown on table VII-9). As a standard of comparison, table VI I-9 also shows the energy needed by a typical single family detached residence in Omaha, Nebr., for 1 year (The exact characteristics of this house are described in volume 11, chapter IV. It can be seen that use of natural gas is the environmentally preferred approach of providing heat and hot water to the house Even the solar total energy system, which provides about 75 percent of all electric needs from a solar collector, is ultimately responsible for more pollution if the remaining 25 percent is from electricity generated from coal. Yet, natural gas supplies are diminishing, so other sources of energy for home heating must be found One possible alternative, shown in the chart, is the use of synthetic gas

A home which burns synthetic gas would be responsible for considerably more air and water pollution than a home supplied with natural gas because coal must be mined and

[15] R R Reuelle, (panel chairman) National Academy of Sciences *Energy and Climate*, Prepublication Draft, Washington, D.C., 1977

Table VII-9.—Ernissions Associated With the Energy Requirements of a Single Family House in Omaha, Nebr.

		Energy consumed in 10^3 kWh	Primary fuel consumed in tons of coal equivalent per year	Pounds of NO_x released annually	Pounds of SO_x released annually	Pounds of hydrocarbons released annually	Pounds of CO released annually	Pounds of particulates released annually	Thermal discharges released annually (in 10^3 kWh)	Pounds of waste solids released annually
Natural gas heat	gas	56	(8.0)	(2)	—	(2)	(4)			
Natural gas hot water	electricity	12	(5.9)	(40-80)	(33-120)	(2)	(2-7)	(1 3-1 20)	(20)	(5200-6400)
Electric a/c	Total	—	13.9	42-82	33-120	4	6-11	13-120	20	5200-6400
Synthetic gas heat	gas	56	(16.0)	(42-97)	(12-56)	(3.5-7)	(76)	(27-320)	—	(5900-11,200)
Synthetic gas hot water	electricity	12	(5.9)	(40-80)	(33-120)	(2)	(2-7)	(1 3-1 20)	(20)	(5200-6400)
Electric a/c	Total	—	21.9	82-180	45-170	5.5-9	8-83	50-440	20	11,100-17,600
Baseboard heating Window a/c . . . . Electric hot water		50	25	160-330	140-480	9	7-28	50-510	85	21,500-27,700
Heat pump Electric hot water		40	19.7	130-260	110-390	7	6-22	40-400	68	17,200-21,300
Solar hot water (11 m^2) Heat pump . . . . Electric hot water backup		32	15.6	100-210	90-300	5	4-17	35-320	54	13,900-17,000
Solar hot water and heating (40 m^2) Heat pump backup . . . . Electric hot water backup		25	12.4	80-160	70240	4	3-14	27-250	43	10,800-13,300
Solar electricity from P.V. cells (100 m^2) Heat pump . . . . Electric hot water		19	9.1	60-120	50-180	3	3-10	20-190	32	8,200-10,100
Solar electric/thermal P.V. system (92 m^2) Heat pump backup . . . . Electric hot water backup		16	7.7	50-100	40-150	3	2-9	20-160	27	6,900-8,500

NOTES — coal gassification from unit fixed bed high BTU plant (see Synthetic Fuels Commercialization Program op cit)
net conversion efficiency of electric generation assumed to be 0 29 and coal assumed to have 12000 Btu l b
– coal plant uses f lue gas scrubber

SOURCE The numbers on this chart are based in part on Information provided by K R Smith John Weyant and John Holdren *Evaluation of Conventional Power Systems* Univ of Cal at Berkeley July 1975. p 119

processed to produce the synthetic gas. Emission levels in this case, however, are still below those associated with burning coal directly for use in electric heating.

As the table shows, any of the coal-based processes for producing residential energy result in the release of large amounts of emissions into the environment, For example, the house heated with baseboard heating units releases 160 to 330 Ibs. of nitrogen oxides, 140 to 480 Ibs. of sulphur oxides, 9 Ibs. of hydrocarbons, 50 to 630 Ibs. of particulate, and nearly 2 tons of solid waste per year. (These amounts include all direct emissions associated with mining, processing, transporting, and burning coal at generating sites.) The solar devices reduce these releases in direct proportion to the amount they reduce electricity consumption.

The analysis has only considered environmental impacts resulting directly from the burning of fossil fuels in mining, transport, or generating processes associated with the production and transmission of energy A number of processes indirectly connected to the construction and operation of both conventional and solar equipment could also have adverse environmental effects — mining and refining materials used to fabricate generating devices, transport equipment, and other energy production apparatus. All of these require energy, and the production of the energy results in environmental damage. These secondary impacts are extremely clifficult to analyze quantitatively because an accurate assessment would require a model broad enough to encompass the entire economy. If solar energy or other energy equipment increases the demand for steel, it is not clear whether the indirect environ mental effects can be computed simply by calculating the energy required to construct this steel and the damage charged to the account of the energy source responsible, i.e., solar, since the use of steel for energy equipment might reduce the use of steel for other types of equipment. Alternatively, the production of additional energy could increase demand for goods in the **economy and in turn stimulate energy consumption, thus increasing environmental damage by other sources.**

Emissions Associated With the Manufacture of Solar Energy Equipment

Since solar energy equipment typically has a higher initial cost than conventional systems, it is not surprising to find that larger amounts of pollution are associated with their manufacture (assuming that the solar devices are constructed using energy derived from conventional energy sources). An estimate of the emissions associated with the manufacture of various types of solar energy devices capable of producing the same annual energy output can be obtained by combining the information in tables VI I-7 and VI I-8 in the previous section with the estimates of emissions associated with different energy sources shown in table VI I-10. Table VI I-11 presents the results of this analysis by indicating the number of months that several types of solar energy systems would have to operate before the emissions associated with providing an amount of energy equivalent to the energy derived from the solar device equals the amount of emissions associated with the manufacture of the solar device. (The conventional system used for comparison is a coal-fired electric generator.) The results are roughly equivalent to the "energy-payback" times computed previously.

The tables show once again the importance of reducing the energy consumed in manufacturing silicon photovoltaic devices used without concentrators.

PROBLEMS ASSOCIATED WITH ONSITE FOSSIL BACKUP

Solar energy systems which rely on onsite combustion of fossil fuels as backup for solar space heating and air-conditioning or electric-generating equipment would have a direct impact on air and water quality since emissions would be released whenever the backup systems were used. The total amount of gaseous and solid pollutants produced by such onsite backup might be no larger than the amounts produced by large centralized generating plants providing equivalent backup services Emissions from the onsite combustion would generally be released much closer to populated areas and, as a result, pollutants could have a greater impact on health.

ONSITE SOLAR ENERGY SYSTEMS AND LAND USE

The collectors employed in many of the onsite solar energy devices discussed in this paper can be either conveniently located on the roofs of serviced buildings or gracefully integrated into the surrounding landscape. In a number of situations this will be impossible, and collector fields will require and area which could probably be put to other purposes. The resulting competition for land will be particularly serious for on-

Table Vll-10.—Primary Emissions Associated With Energy Resources Available for Residential, Commercial, and Industrial Consumers (pounds per thousand kWh of heating value reaching consumption site)

	SO_2	NO_x	CO	HC	Partic-ulates	Waste Solids	Reference
1. Residential systems							
—Natural gas .	nil	**0.3**	0.7	**0.03**	nil	nil	(1)
—Oil (0.2%` sulphur)	**0.75**	**0.3**	0.10	0.06	0.10	nil	(1)
—Electricity (from a ., coal-fired baseload generating plant).	**2.8-9.6**	**3.3-6.6**	0.14-0.6	0.11-0.19	1,1-10.2	431-533	(2)
—Synthetic gas ., ...	**0.22-1.0**	**0.75-1.73**	70.10 1.4	0.063 - 0.126	0.49-5,78	106-199	(1) (3),(4),
II. Commercial and industrial systems							
—Natural gas	nil	0.34	0.68	**0.03**	nil	nil	(1)
–Oil	0.75	1.71	1,71	**0.68**	**0.34**	nil	(1)
—Coal (western-stoker)	3.07	1.88	0,20	**0.06**	**16.0**	28.3	(1)
—Coal (high sulphur)	4.10	1.71	2,39	**0.06**	**0.20**	123.9	(1)

"Assumes a lime-scrubber, flue-gas, desulfurization system.

SOURCES: 1 Evaluation of the Feasibility for Widespread Introduction of Coal into the Residential and Commercial .% ectors, Volume I, prepared by the EXXON Research and Engineering Company for the Center fOr Environmental Quality Draft report, dated April 1977, p. 8

2- Evaluation of Conventional Power Systems, prepared by the Energy and Resources Program of the University of California at Berkeley. July 1975, P 119

3 Kirk R Smith, John Weyant and John Holdren " Evaluation of Conventional Power Systems, University of Call fornia at Berkeley, July 1975, P 136

4 Synthetic Fuels Commercialization Program Draft Environmental Statement, Synfuels Interagency Task Force on Synthetic Fuels, Volume IV. December 1975, PP IV-12 and IV-40

Table VII-11 .–" Payback Time" for the Emissions Associated With the Manufacture of Solar Energy Systems

(expressed as the number of months the system must operate to displace energy which, if generated in a coal-burning electric generating facility equipped with a scrubber, would equal the emissions associated with the manufacture of the solar device)*

Solar Energy System

mission Type	Pond (thermal only)	Flat-plate (thermal (only)	Flat-plate (silicon photovoltaic)	Concentra-ing photo-voltaic with silicon cells (electric only	Concentrator with high efficiency heat engine. electric only	thermal only
1. SO_2	.03-1.4	0.6-1.1	3.3-106	6.1	2.9	1,1
2. NO_x	.05-1,8	0.6-1.3	3.4-106	6.0	2.8	1.1
3. co	0.5-15	3.7-7.5	5.1-109	26	14	5.1
4. Hydrocarbons.	0.3-8.0	2.0-4.1	3.9-109	15	7.6	2.9
5. Particulate. . .	.08-4.4	1,7-3.4	3.7-108	24	13	5.0
6. Waste solids . .	.02-0.6	0.3-0.6	3.2-106	2.5	0.9	0.3

'These times assume that emissions associated with electric generation are the median of the values given in table VII 10 site solar systems where the required land is close to populated areas. The land clearing required for collector fields under these circumstances and the denial of alternative uses of open land close to living areas constitute by far the largest negative impacts of this type of onsite solar technology. Conventional energy sources also require substantial land areas for mining, and for generating and transmitting power, but much less land is required per unit of energy produced and the land, for the most part, is remote from densely populated areas.

The land use issues cannot be dealt with in general terms, The eventual outcome of each case will depend on the skill and imagination of architects and planners as well as the tastes and values of the individuals and communities served by solar equipment.

Negative impacts of collector fields on land use will be evaluated in three main areas:

- building orientation and landscaping
- community design
- the environmental effects of collector fields.

The following discussion will point out some of the anticipated problems in this field, and outline some possible techniques for resolving difficulties.

Land Use Impacts Associated With Building Orientation and Landscaping

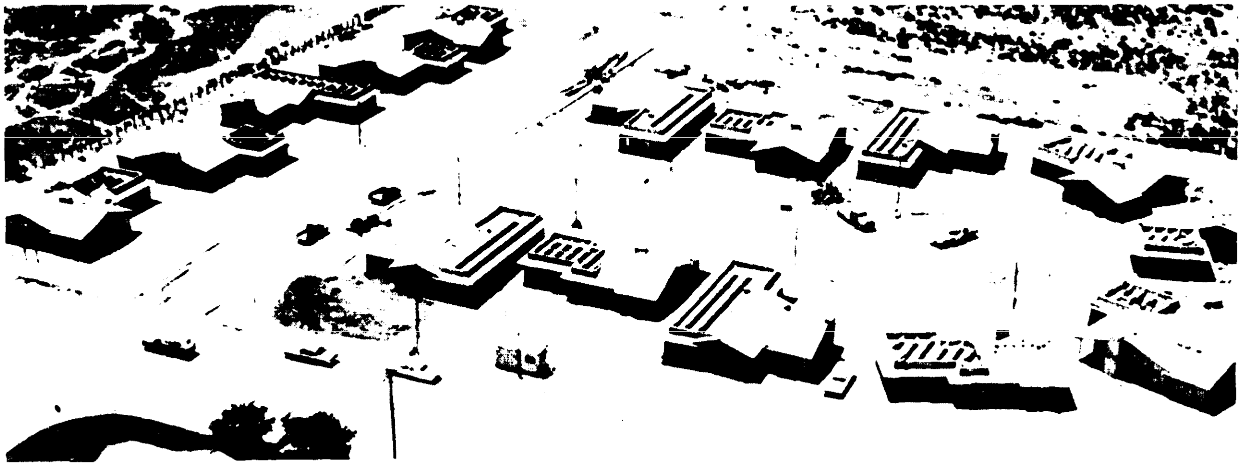
The environmental impacts of solar energy devices can be reduced in most cases by placing as many collectors as possible on the roofs or walls of buildings. (The impact on building design and appearance and the amount of area available for different types of architecture will be discussed in the next section.) In many cases, however, it will be impossible to find enough area on buildings for an efficient solar system Existing buildings may be shadowed during the day or may have sloping roofs which are not properly oriented for efficient solar collection A detailed study of the number of buildings In different regions having proper solar orientations would be extremely valuable in assessing the potential market for retrofitting existing structures with solar equipment.

Orienting new buildings to maximize opportunities for collection of available sunlight can create problems. In most new communities the orientation and placement of buildings is dictated by the location of sewers, water lines, electric mains, local topography, main access roads, etc. The direction of the Sun is rarely a consideration. Proper orientation of buildings for solar energy purposes could increase the cost of houses in the community; for example, services for providing utilities might have to cover greater distances, driveways might have to be extended to permit cars to enter garages or carports which were not facing the street, etc. These, and other aspects of community design, would promote energy conservation which inevitably will become more important to buyers as the price of energy increases (see figure VII-3).

In some situations a building constructed to take maximum advantage of the Sun will not supply enough roof or wall area for the required collectors. The site itself may be shadowed during the day, or basic requirements of the building may limit available alternatives. In a highrise building, for example, the roof area will not be adequate for more than a simple solar hot water system, but more area can be obtained for solar collector if the south-facing wall is partially covered by collectors (vertical collectors gather 50 to 75 percent of the energy which would have been provided by collectors with the same surface area oriented at an optimum angle on the roof).

Since the combination of roof and wall areas may not adequately provide more than a small fraction of the energy requirements of some buildings, additional collectors must then be placed in arrays on the ground It may be preferable to locate these additional collectors close to the buildings served by the solar equipment, since this would maximize alternatives for

Figure VII-3–A Small Housing Development Using Solar-Heating Devices



SOURCE Mother Earth News, No 45, May-June 1977, p 1090

multiple use of the collector areas and minimize the cost of transporting the energy produced by the collectors.

Many proposed multiple land uses would coordinate collector fields with other land uses. For example, solar collectors could shade the upper level of parking lots (as shown in figure VI 1-4), or in other cases the collectors could shade patios or play-grounds. Lawn or shrubs can be grown under the collectors as figure VI I-5 shows.

Wide spacing of collectors, or the placement of collectors on poles over parking lots, will increase the price and possibly reduce the efficiency of the collector system. These effects must be carefully weighed against the advantages of reducing the system's land-use impacts. There is room for much creative work in this area which will require a judicious mixture of engineering, landscaping, and building design concepts.

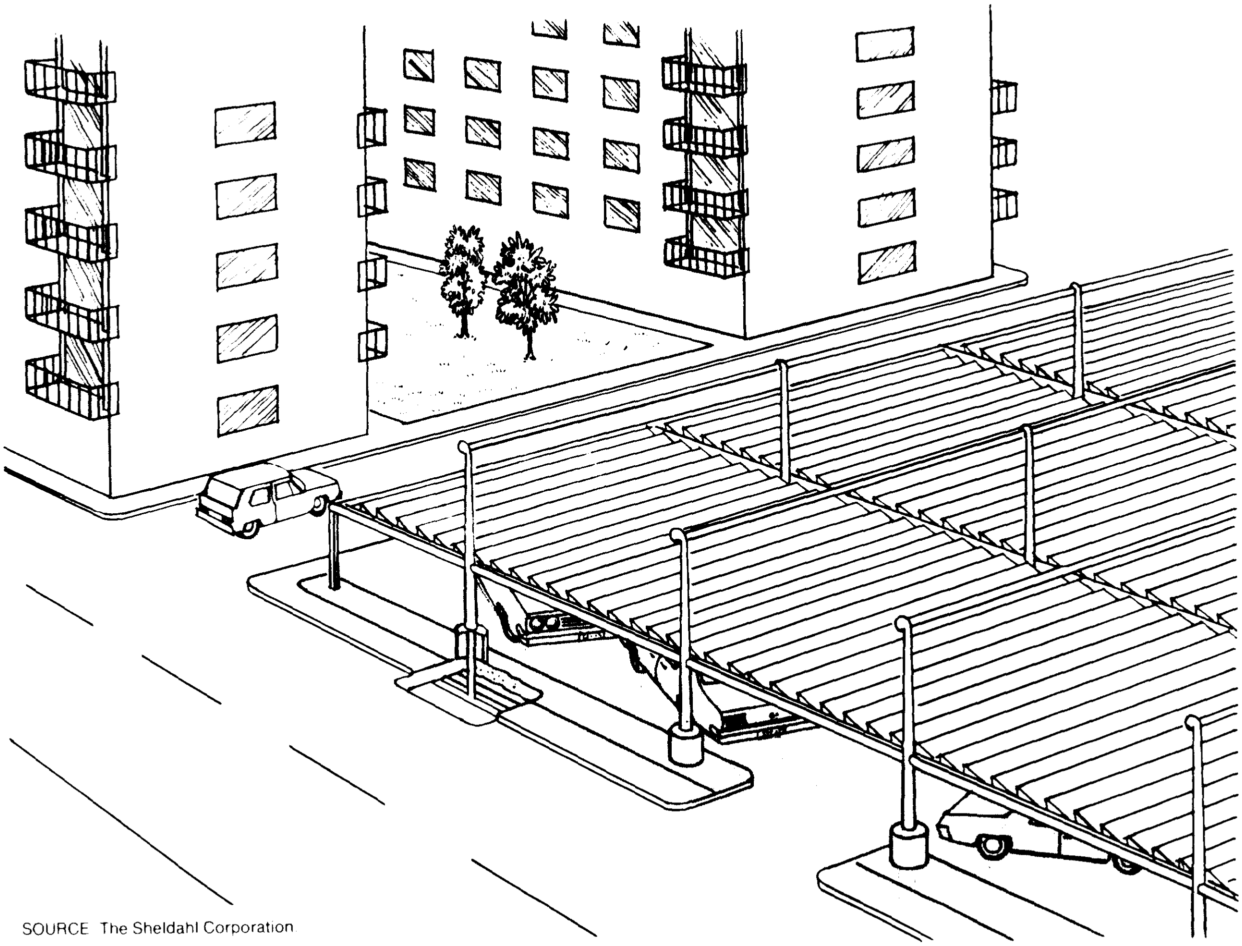
Solar Collectors and Community Design

To design a new residential community or commercial area for the maximum use of solar energy is easier than to implement solar collection in individual situations since, for example, plans can be made to orient buildings properly, height restrictions can be used to minimize shading, and areas can be set aside for collector fields to reduce their disruptive effect on the community and maximize the likelihood of multiple land use. A variety of community designs maximizing the use of solar energy are possible, but problems are associated with each.

If it is not physically possible or economically desirable to locate collectors close to building sites, the question of locating sufficient collector areas arises. **It** must be determined, for example, whether the system should be located in a remote area, generating only electricity, or whether the system should be located closer to the community or industry served, and generating thermal energy as well. Remote location of the solar energy systems would permit the use of less expensive land, and would avoid the problems associated with competing for scarce open areas close to population centers but it would increase transmission costs and possibly reduce design flexibility (see chapter IV).

Another possibility applicable especially in new developments, would be to centralize the collector field and distribute the community around it. Multiple land uses would be encouraged by allowing centralized parking or some recreational areas to be combined with collector fields but the reduction in the density of the community could result in added expense for other urban services (roads, utilities, etc.).

Figure VII-4– Tracking Collectors Mounted Over a Parking Lot



SOURCE The Sheldahl Corporation

The prohibitive expense or simple unavailability of land close to population centers will be major constraints on the use of onsite solar facilities in or near existing communities. If solar collector fields are to be integrated into population centers, factors such as population patterns, the size and location of trees, the types of buildings found in the area, etc., must be considered.

The use of solar energy in individual buildings can be encouraged by intelligent community planning, In the computer-modeled residential community of 30,000 persons examined in this study, for example, 300,000 to 500,000 m^2 of collectors could be placed on the roofs of buildings (depending on the slope of the roofs) and an additional 400,000 to 600,000 square meters of a area would be available over parking lots and perhaps 250,000 m^2 would be available over highways. If all of these areas were covered with silicon photovoltaic devices and if adequate storage were available a continuous output of 17 to 28 MW in Omaha, Nebr, and 23 to 37 MW in Albuquerque, N Mex , could be provided. While this would not be adequate for all of the community's needs, it would greatly reduce the land requirred for ground-mounted collector arrays.

It **may** be very difficult to design a solar community in a heavily forested area and trees in existing neighborhoods may present prohibitive problems for some sites. A great

Figure VII-5.—Vegetation Growing Under Arrays of Solar Collectors

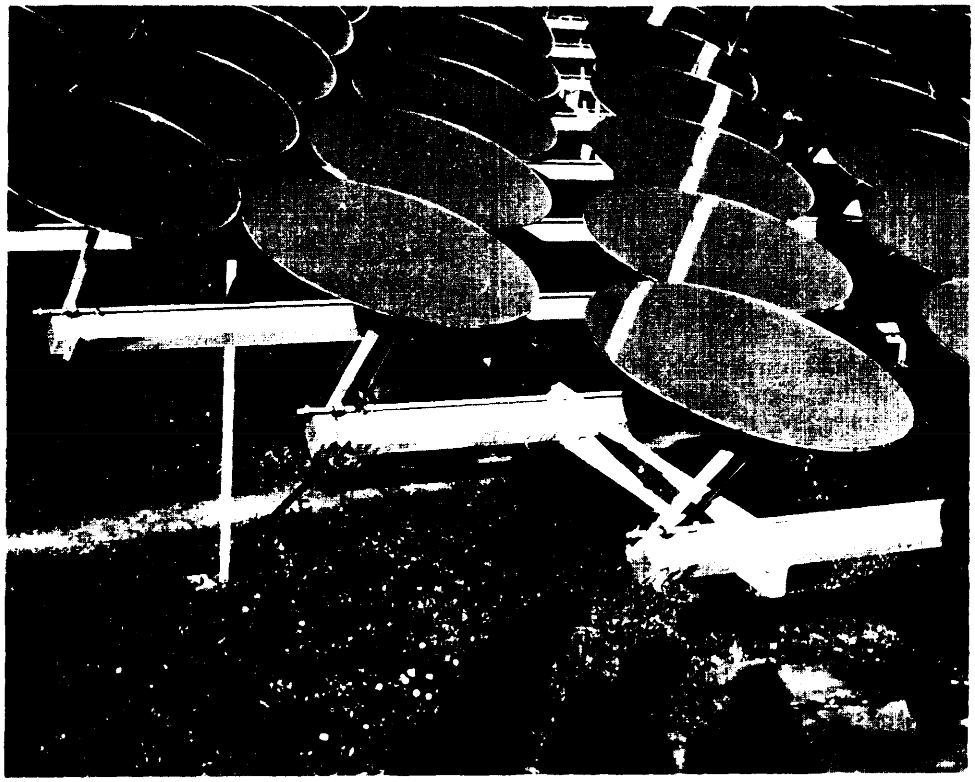


Photo by John Furber

a) Professor Francia's Solar Steam Generating Plant, Genoa, Italy.

b) Flat-Plate Collectors at University della Calabria, Cosenza, Italy.

SOURCE G Francia, University of Genoa, Italy deal of thought will have to be given to this issue in some parts of the country and there may be no easy solution

THE ADVERSE ENVIRONMENTAL EFFECTS OF COLLECTOR FIELDS

If land must be cleared exclusively for use as collector fields, the effect on the local environment could be very great Impacts include the loss of existing buildings, the destruction of ecosystems, and the noise, dust, and disruption of the clearing activity. **If** the land were originally forested, the fundamental ecology of the region would be affected While it is possible for vegetation to grow under collector fields, so that some low plants and small animals could continue to Inhabit the area, the mixture of species would no doubt be very different from those which would have inhabited the region had it remained undisturbed Moreover the access roads required to maintain the collectors would disturb any new species which did inhabit the area. If the land were originally grassland or desert, however, the impact of the solar devices might be less, although it in no way could be considered negligible. Some change could be expected in local temperatures simply because the absorptivity of the region would be changed by the presence of the collectors. The effects caused by solar arrays, however, are no different from the changes which would occur from other types of development (e. g., with a parking lot or with a farm field). Any harm to a relatively undisturbed natural environment **in the immediate vicinity of populated areas must be considered to be particularly serious, because such areas are rapidly disappearing.**

LAND USED BY CONVENTIONAL GENERATING SYSTEMS

A conventional coal-fired electrical generating system requires land for mining, train lines to transport the coal, land for the generating facility, and land for transmission and distribution of power.

Table VI 1-12 indicates the amount of land which would be required for strip-mining coal and for transmitting power. Each square meter of strip-mined land in the Eastern United States yields enough coal to provide about 2,000 kWh of electric energy. A silicon photovoltaic array placed over the same square meter would need to operate

Table VII-12. —Land Required for Strip-Mining Coal

	Eastern strip mines		Western strip mines	
	1974	1985	1974	1985
Acres/year mined	57,348	69,704	7,140	16,330
kWh/m^2	2,150	2,144	5,744	10,627
Years of solar operation to provide equivalent power in the same land area:				
Albuquerque	14	14	38	69
Omaha.	22	22	60	111

Assumptions:
— 29 percent efficiency of generating and transmitting electrlcity
— Silicon photovoltaic cells on non-tracking racks spaced to avoid shading (land coverage ratio = 52 percent in Albuquerque and 43 percent in Omaha),
— 12,000 Btu / lb coal
— Coal production statistics based on OTA forecasts.

between 14 and 22 years to provide an equivalent amount of energy. In the West, where thicker coal seams are found, a square meter of strip mine could provide between 6,000 and 10,000 kWh of power and a collector would need to operate 40 to 100 years in the same region to provide an equivalent amount of power.

Long distance electric transmission also requires a considerable amount of land. The Electric Power Research Institute estimates, for example, that by 1990 electric transmission lines will require a right-of-way of $2.1 \times 10^{10} m^2$ (about 220 billion ft^2). " If this area were covered with 10-percent efficient solar cells, about 4×10^{12} kWh (1 3.6 Quads) of electricity would be produced annually, It is possible to use the rights-of-way of transmission lines for purposes other than transmission — multiple land use is also possible with the solar equipment but somewhat more diff i cult and expensive to undertake.

Another interesting point of reference for the land use impact of solar equipment is the land covered by surfaced roads in the United States. There were about 5.9×10^{10} m^2 of such roads in the United States in 1975.[17] Covering these surfaces with 10-percent efficient cells would produce 11.4×10^{12} kWh annually or 39 Quads. United States electricity consumption in 1976 was 2×10^{12} kWh or 6.8 Quads.

The direct comparisons of solar and conventional land use cannot be conclusive, These comparisons do not account for either the quality of the land impacted by the two types of systems or the fact that the impacts of onsite solar facilities are typically closer to populated areas than coal mines or larger transmission facilities. Land-use impacts in populated areas are generally more regulated by local zoning laws and by the public opinion associated with highly visible local activities, while activities in remote areas are generally exempt from regulation.

" EPRI Technical Assessment Guide, August 1977.

[17] Federal Highway Administration, Department of Highways, 1974. (Calculation assumes average surfaced road width is 40 feet)

IMPACT ON BUILDING DESIGNS

BACKGROUND

Unlike conventional heating and cooling equipment, solar collectors mounted outside of the building can be highly visible. Concern about the appearance of solar installations and the effect of this appearance on the resale value of the property to which it is attached, may be a significant barrier to the near-term commercialization of onsite solar energy equipment. In a recent survey of lending institutions, 43 percent of the officials interviewed stated that concern about the "bulkiness or unusual appearance" of solar devices would be of some concern to them in evaluating a loan application for solar energy and 19 percent stated that this would be a "primary concern.'" [18]

The difficulty is traceable in part to the lack of examples of equipment on standard types of housing and to the fact that most publicized devices are either highly experimental (without great attention being paid to appearance) or are installed on expensive, custom-built homes. With some care, even buildings which are optimized for solar energy by having large roof areas with steep slopes, large south-facing windows, thick walls, and other special features, can be made attractive.

[18] Regional and Urban Planning Implementation Inc , *financing the Solar Home: Understanding and Improving Mortgage Market Receptivity to* Energy *Conservation and Housing Innovation, June* 1976, p. 83

integrating active and passive solar energy systems into building design will require some imaginative architecture and the results will depend on regional tastes. It is possible to design conventional buildings with solar energy devices with a minimal impact on building appearance (see figures VI I-6 and VI 1-7). Collector colors can be matched to root colors.

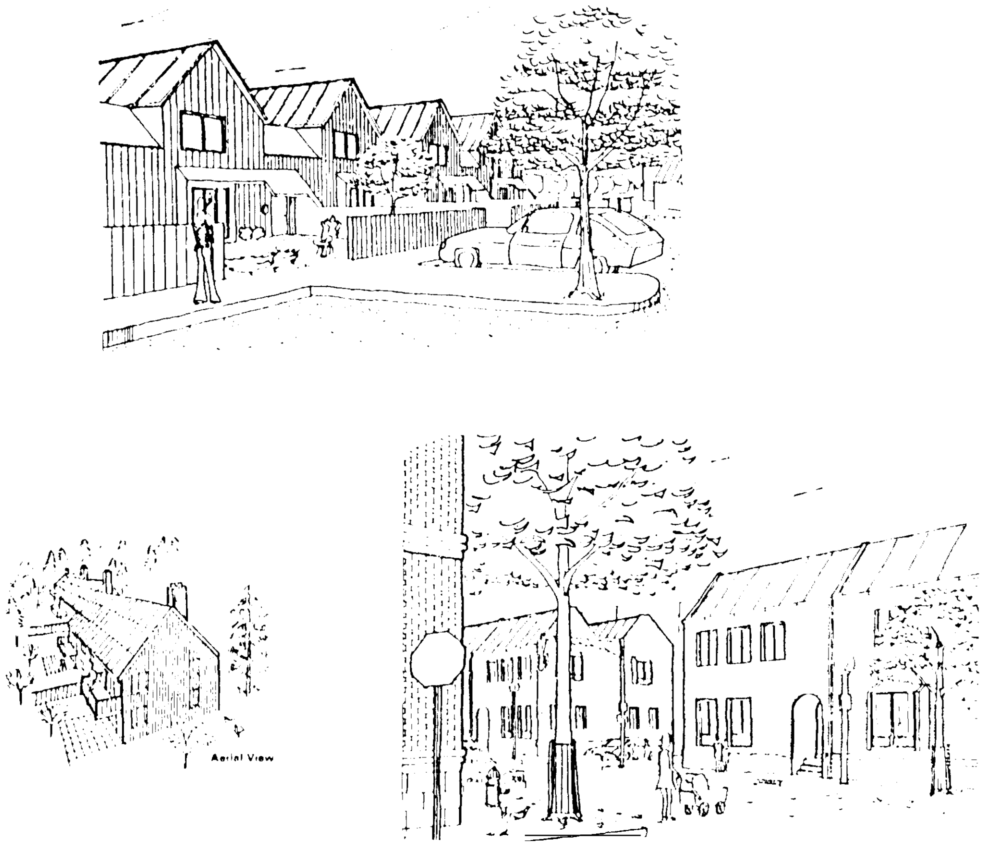
The feasibility of retrofitting existing homes with collectors as shown in the figures will depend on local conditions. Shading by improperly placed trees and other buildings present the most serious problems, and improper roof orientation or slopes could impair system efficiencies.

The roofs of standard buildings are not designed to optimize the efficiency of solar equipment. Roof pitches may be wrong, the roof area may be too small, the framing of the roof may be insufficient to support a collector, and the orientation of the structure may be incorrect. Table V **I 1-13** indicates the roof areas available in standard building designs, and the areas which can be provided with roof slopes at more optimum angles for solar collection. A number of imaginative designs have been developed durin$_g$

Figure VII-6– Techniques for Integrating Solar Collectors Into Conventional Designs for Single Family Residences

SOURCE Solar Dwelling Design Concepts op cit pp 79.83, 89

Figure VII-7– Techniques for Integrating Solar Collectors Into Conventional Designs for Townhouses and Low Rise Apartments



SOURCE Solar Dwelling Design Concepts op cit pp 91-93

the past few years which **can provide large** collector areas at proper orientations. Two such designs are illustrated in figures VI I-8 and VI I-9.

The less attractive collector systems, such as tracking collectors and rack-mounted flat plate collectors, can be shielded from ground view with simple screens around the building perimeter, but in some installations it will be clifficult to mask the systems completely. (See figure VI I-10). Screens would add to the cost, but would probably increase the reliability of tracking systems by also serving as wind screens. As society has apparently become accustomed to buildings with all manner of gadgetry on roof tops (vents, antennas, and air-conditioning cooling **towers), it would be difficult to argue that the addition of solar devices would seriously degrade the appearance of buildings.**

Wall collectors provide another means of increasing the collector area. Large, tall buildings, such as high-rise apartment buildings, are particularly well suited to wall collectors. Wall collectors generate about 75 percent of the energy that the same collector area would generate if tilted (in Omaha, Nebr.), so their use may be economical in some instances. Wall collectors, moreover, may not alter the appearance of some types of buildings, e.g. , glass-walled offices, **or** apartments (see figure V I 1-11)

Table VII-13.—Potential Areas for Collectors on Typical Buildings*
(in square meters)

	Albuquerque	Boston	Ft. Worth	Omaha
Shopping **Center**				
Building Roof				
Horizontal roof area .	28,800	28,800	28,800	28,800
Slanted racks on horizontal roof	15,261	12,171	16,520	12,626
Parking Lot				
Land area, ...	90,000	90,000	90,000	90,000
Slanted racks above cars . , . .	47,691	38,034	51,624	39,456
196-Unit high rise				
Building Roof				
Horizontal roof area . .	1,883	1,883	1,883	1,883
Slanted racks on horizontal roof . . .	998	796	1,080	826
500/0 of southern wall.	1,500	1,500	1,500	1,500
Parking Lot				
Land area.	7,840	7,840	7,840	7,840
Slanted racks above cars	4,154	3,313	4,497	3,437
36-U nit low rise				
Building Roof				
Horizontal roof area .	1,270	1,270	1,270	1,270
Slanted racks on horizontal roof	674	537	729	557
Parking Lot				
Land area.	1,440	1,440	1,440	1,440
Slanted racks above cars . .	763	609	826	631
8-Unit townhouse				
Building Roof				
Horizontal roof area .,	620	620	620	620
Roof slope at latitude	756	837	731	824
Typical roof slope	327	327	327	327
Slanted racks on horizontal roof	328	262	356	620
Parking Lot				
Land area, ...,	320	320	320	320
Slanted racks above cars	170	135	184	140
Single family house				
Building Roof				
Horizontal roof area	83	83	83	83
Roof slope at latitude	101	112	98	111
Typical roof slope .	44	44	44	44
Slanted racks on horizontal root.	44	35	48	36
Carport				
Horizontal roof area .,	28	28	28	28
Roof slope at latitude	34	38	33	37
Slanted racks on horizontal roof . .	15	12	16	12

"See volume II. chapter IV for a detailed description of the buildings

Figure VI I-8.—A Residential Building With Optimized Solar Roof Pitch and Orientation

PHOTO: Reprinted from *Popular Science* with permission 1976 Times Mirror Magazines, Inc

ROOF PITCH AND ORIENTATION

Table VI 1-14 indicates how the energy collected by flat-plate collectors varies as a function of the angle of the roof and orientation of the building. It indicates the "useful" output of thermal collectors (e.g., the output which is actually applied to heating space and water), the total thermal output (which includes thermal **energy which must be discarded because the storage is filled), and the electric output which** could be provided by a flat-plate silicon photovoltaic **ar**ray. In all three cases, the direct output is shown and the results are normalized for comparison with the optimum roof design.

The useful thermal output for heating and hot water is optimized when the roof in Omaha is sloped at an angle of 560 (which is 150 greater than the latitude), and the collector is oriented due south. If the collector faces south but is tilted at an angle more typical of residential roofs (a drop of 4 feet in a run of 12 feet) the performance would be reduced **by 18 percent or, equivalently, the amount of collector area required** for an equivalent output would need to be increased by 22 percent. **If** the house with a collector tilted at the latitude angle (4 I 0, were **oriented** due west instead of south, the energy received would be reduced by 11 percent. If both effects were combined in a

Figure VII-9. —A Commercial Building Designed To Optimize Roof Pitch and Orientation

PHOTO Courtesy of J Bayless, President, Solaron Corporation, 1976

"worst possible house for solar cillection," and a house with a standard **"4/12" slope were** facing due west, the energy received per unit collector area would be reduced 39 percent **or** the required collector area would be Increased by 64 percent. [Even a house with a collector on a horizontal roof would receive more energy.) A number of other combinations of roof pitches and building orientations are shown for comparison.

The output of photovoltaic devices is much less sensltive to the roof orientation, A south-facing roof tilted at the "4/12" slope would receive 98 percent of the energy received by a house tilted at an optimum angle. A west-facing wall would receive 49 percent of the energy of the optimized system, the "worst-case" house roof 86 percent.

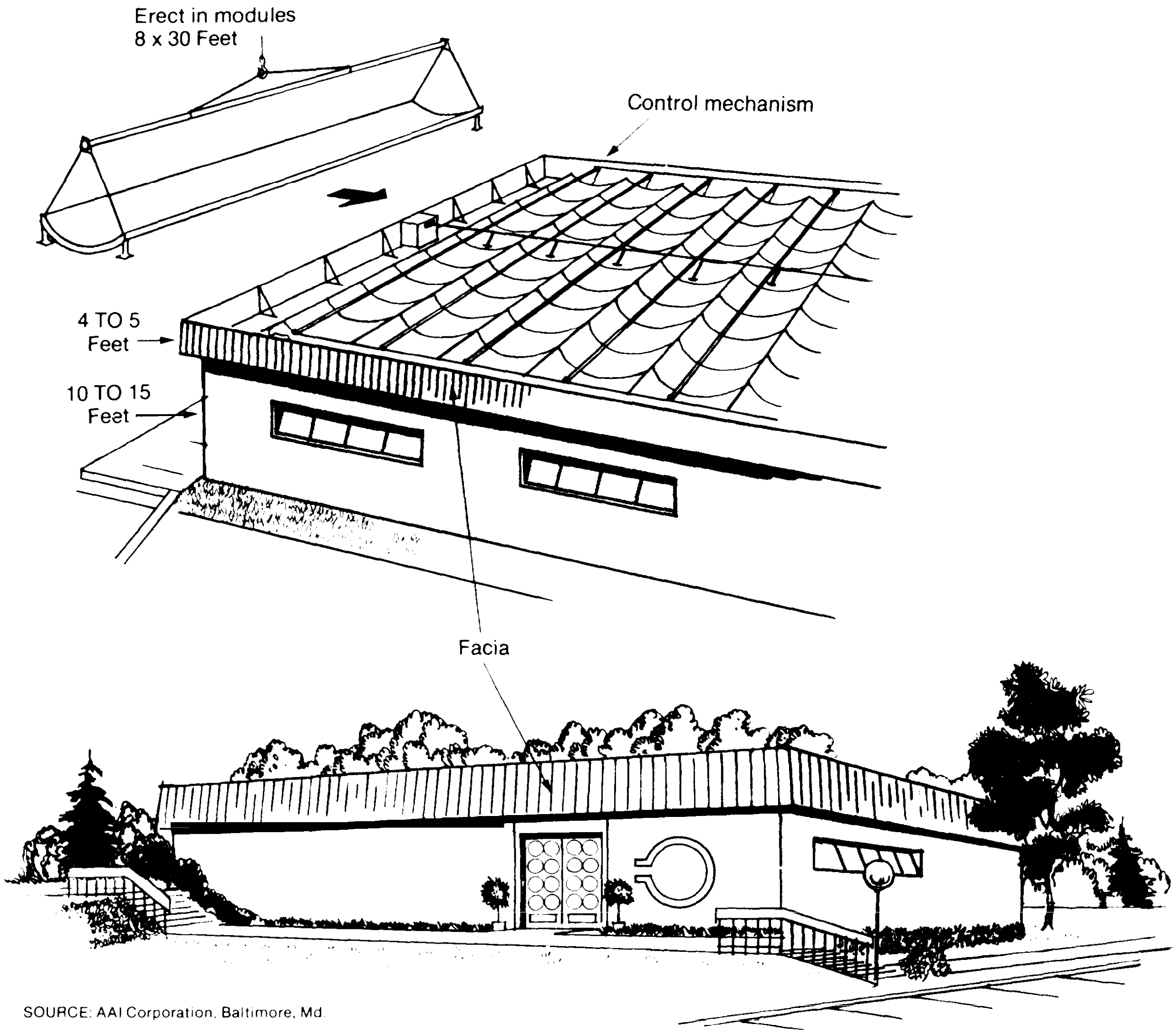
This analysis indicates that a large fraction of existing buildings could be retrofitted with solar systems without either a major sacrifice in system efficiency or alterations in the roof lines. It also means that architects have considerable latitude in designing solar structures; deviating from optimum orientations will increase the cost of collector systems, but designers may feel that this added cost is justified if it allows a more attractive building plan, if it improves the orientation of the building with respect to scenery, or if it reduces the overall construction cost of the building.

SPACE FOR STORAGE

Storage Tanks

The size of required heat storage tanks varies with the type of storage sought: over-

Figure VII-10—A Proposed Installation for a One-Axis Tracking Collector



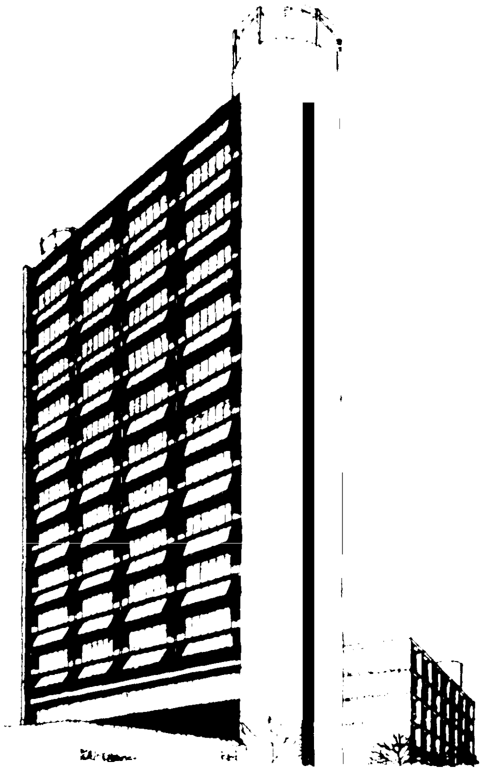
SOURCE: AAI Corporation, Baltimore, Md.

night storage, backup capacity for 2 or 3 days to allow for cloudy weather, or seasonal storage. For overnight heating and hot water needs (assuming an average house in Omaha on a typical winter day), a 500 to 1,000 gallon water tank is sufficient, For 2 to 3 days storage, that capacity would have to be doubled or tripled; seasonal storage would require a 50,000 gal Ion tank,

For the 196-unit apartment building (again using the needs on a typical winter day in Omaha), overnight storage would require a 25,000 to 50,000 gallon tank; 2 or 3 day storage capacity would be twice or three times that, and seasonal storage would require a 3 to 6 m i l l ion gallon tank

All but the smallest of these tanks would probably be buried close to building sites, thus minimizing land and building space requirements. In the case of new housing, it might be more practical to bury the tank directly under the basement of the house, creating a sort of sub-basement. On most sites, there should be adequate space for

Figure VI I-1 1 .—Use of Collectors on the Vertical Wall of a High Rise Hotel



SOURCE The Radisson Hotel Corporation St Paul Minn expected operational date September 1978

even the largest tanks The huge tanks required for seasonal storage in apartments, for example, could be buried in an area covering less than half the area of the apartment's parking lot.

A number of storage media other than water are available: oils, salt cornpounds, organics, and concentrated solutions. The alternate fluids have the advantage of requiring less volume and hence less storage space, but the disadvantage of greater expense, flammability, or the requirement of separate specially constructed tanks must be considered Since the tank is buried, its size is not an aesthetic factor, and water tanks are probably the most practical for the residential and commercial applications discussed here.

Electrical Storage Devices

Advanced collector systems may produce electrical energy for a residential or commercial building as well as thermal energy, and onsite storage of electrical energy in batteries may be a necessary component of such systems.

The space required by the batteries is, by itself, not a major concern. Lead-acid batteries require about 1 cubic foot of space for each kWh of storage capacity. Thus, 20 kWh of storage capacity would require 20 cubic feet of space, most likely in the basement of the home (less than a 3-toot cube). A bank of batteries with this capacity would be dangerous, particularly in residential uses where children are present, and should be stored in a locked room or cage of some

Table VI.14.—Thermal and Electric Outputs of Flat-Plate Collectors in Omaha, Nebr., as a Function of Tilt Angles (with respect to horizontal) and Orientation (with respect to south)

Orientation	Annual thermal output of collector (kWh/m^2)	Ratio of thermal output to thermal output at optimum collector orientation	Annual thermal output usable for heating and hot water (kWh/m^2)	Ratio of useful thermal output to useful thermal output of collector at optimum orientation	Annual electric output of silicon photovoltaic cells (kWh/m^2)	Ratio of electric output to output at optimum collector orientation	Electric output in December (kW1m^2)	Electric output in June (kWh/m^2)
South Tilt = Lat + 15°	590	.91	410	1.00				
South Tilt = Lat	643	.99	399	.97	226	.99	14.6	21.3
South Tilt = Lat -10°	647	1.00	378	.92	228	1.00	13.6	22.6
South Tilt = Lat -23° (4/12 roof slope)	613	.95	335	.82	224	.98	11.9	23.7
Tilt = Lat	598	.92	364	.89	216	.95	13.2	21.3
Tilt = Lat -23° (4/12 roof slope)	470	.73	249	.61	195	.86	8.1	23.1
Horizontal	502	.78	260	.63	205	.90	8.7	24.0
S. Vertical	326	.50	324	.79	127	.56	6.3	13.8
W. Vertical	169	.26	158	.39	112	.49	5.0	13.0

Assumptions:
- **thermal output computed assuming a tubular flat plate (operating characteristics of the collector assumed in the analysis are shown in volume II chapter IV).**
- **useful output of the collector was computed assuming that a heating and hot water system with 40** m^2 of collectors is used in connection with 1,000 gal of hot water storage and serves the typical single family house whose characteristics are outlined in volume II, chapter IV. Electric resistance heating and electric hot water heaters were assumed to provide needed backup.
- the photovoltaic system analyzed was a passively cooled silicon system with a cell efficiency of 0.14 at 28° C and a heat removal factor (K_e) of 0,025 kW/m^2-"C.
- the results are integrated over a full year.

SOURCE: Prepared by OTA.

sort. The 196-unit apartment building would need a I most 3,000 kWh of electrical storage for one day's needs (about a 15-foot cube).

In addititon to the security needed for a large array of high-yield batteries, the system should be vented to protect against the buildup of potentially explosive hydrogen and the toxicity of other gases which are byproducts of lead-acid battery use (see chapter XI, Impacts on the Environment section)

OTHER BUILDING IMPACTS

Onsite energy systems will undoubtedly require more interior building space than conventional heating and cooling systems. Even the simplest hot water systems require space for pumps, controls, and larger hot water tanks. More complex heating systems will require larger tanks as well as additional pumps, controlled valves, and heat exchangers. While the tanks can be buried outside the building, space will be required for the supporting equipment. In most cases the space needs will be minimal.

More complex systems using heat engines would require substantially more space, either in the building or in sheds close to the building served, A solar heat engine large enough to operate an air-conditioning system, for example, would be approximately as large as the air-conditioner which it operates An engine providing electricity as well as air-conditioning would be even larger. Space requirements within buildings could present serious difficulties **in these cases.**