Chapter II

OVERVIEW OF ONSITE SOLAR Technology AND SUMMARY OF ECONOMIC ANALYSIS

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LIST OF TABLES

Chapter II

Overview of Onsite Solar Technology and Summary of Economic Analysis

INTRODUCTION

This study examines the cost and performance of a cross-section of onsite solar energy systems designed to meet all or part of the energy requirements of five different categories of energy customers:

—A two-story, single family, detached house with approximately 1,700 square feet of living area.

—A 10-story, 196-unit, high rise apartment building.

—A shopping mall with approximately 300,000 square feet of commercial space.

—A residential community consisting of a mixture of single family houses, townhouses, low rise and high rise apartments, and commercial facilities.

—A series of industrial installations requiring differing amounts of process heat and electricity.

The systems were examined in four U.S. cities— Albuquerque, Boston, Ft. Worth, and Omaha– chosen to represent a range of different climatic conditions (both in terms of the availability of the solar resource and the heating and cooling demands). The cities also represent a spectrum of different electricity and fossil fuel costs; this was important since the cost of energy from conventional sources around the country tended to show greater variation than the amount of available sunlight. The results presented in this chapter are limited to an analysis of the costs of hypothetical systems operating in Albuquerque and Omaha.

The technologies chosen for analysis include devices which supply:

– Hot water for domestic or industrial use;

– High-temperature fluids for industrial-process heat;

– Hot water and space-heating;

— Hot water, space-heating, and air-conditioning;

– Electricity (from solar cells or heat engines); and

— Electricity and thermal energy (using total energy or cogeneration systems).

It was not possible to review the performance of all possible systems for onsite systems designed to meet onsite energy needs with direct solar energy, and it was not possible to optimize the performance of the systems selected. The analysis presented here is intended only to establish the credibility of different proposals and to make broad comparisons between competing concepts.

This chapter only summarizes the results of the **analysis; a much more complete assessment of the technologies represented is reported in chapters VIII-XII of** this volume. **Volume II presents a much more detailed review of the assumptions made in the study, the methodology employed, and reports the results of analysis of a much larger number of cases than can be summarized here.**

METHODOLOGY

While the cost of different energy sources can be compared in a number of different ways, the comparisons presented here were all made by computing the average monthly bill paid by the ultimate consumer of the energy. This consumer might be the owner of a single family house, a tenant in a high rise apartment, or an individual purchasing a product or service from a commercial or manufacturing facility. These calculations were made as follows:

1. Systems were compared on the basis of their ability to meet the same set of final or "end-use" demands for energy. In the case of a single family house, for example, this means providing energy for domestic hot water, space-conditioning, and electricity for motors and other miscellaneous uses. If the solar energy equipment was unable to meet the demand (or was not designed to meet some of the demands), these energy needs were met by using electricity or fossil fuels from conventional sources. The billing for this conventional energy was made on the basis of actual rates currently charged in the region.

2. All comparisons were made on the basis of "life-cycle" costing methods. This required an estimate of all outlays for operating and maintaining equipment, electricity and fuels purchased, taxes, and major replacements over a selected 30-year period (1 985-201 5), as well as an estimate of the initial cost of the system. Estimates of the electricity and fuel required by the different system designs were obtained by using a computer model capable of calculating the energy needed by each building type for each hour of the year (described in detail in volume I I). When solar devices were used, the computer model also provided hourly estimates of the amount of solar energy available. The analysis was based on weather data taken in the four cities in 1962 (1963 for Boston).

   An accurate estimate of lifecycle costs cannot be made by simply adding up all of the outlays made during the 30-year interval chosen for comparison. A dollar spent in the 30th year will not be as important to the owner of the system as a dollar spent during the first year of the system's operation —since, in principle, the payment required in the 30th year could be met in the first year of operation by investing an amount much smaller than a dollar in an account earning compound interest. Cost comparisons were therefore made by comparing the "present value" of all expenditures, where present value is defined to be the amount which, if invested at interest in the first year of a system's operation, would be able to meet all cash requirements for energy (including the initial cost of the system). Since each owner will have access to different types of investments, a different effective interest rate must be used to compute the present value of outlays for each owner.

3. It was assumed that consumers compare costs on the basis of the "present value" of their energy-related payments and expect to earn a 10-percent return (after taxes) on all investments. Payments consumers made were estimated by computing the charges which would be levied assuming the utilities or apartment building owners earned the same rate of return on their energy investments that they earn on other types of investments.

Using this method of comparing consumer costs, of course, does not imply that consumers will actually select energy equipment on the basis of such a sophisticated financial analysis. Purchasing decisions are likely to be heavily influenced by first costs, the customer's estimate of a system's reliability and convenience, and the skill with which the item is marketed. No attempt was made, therefore, to anticipate actual consumer behavior. The present value technique is, however, the most accurate technique available for evaluating the real cost of energy, and it could be used to market energy-related equipment in the future. The major uncertainty in the method is the choice of the consumer's expected return on investments,

4. All systems for meeting the fixed set of end uses were compared as integrated systems. This meant, for example, that the performance of solar collectors and the heating and cooling demands of energy required to meet the heating and cooling needs of buildings were computed on an hourly basis assuming that the buildings were operating in a realistic set of climatic conditions.

While computing the cost of many types of solar energy systems is treacherous because of differing estimates of the cost and performance of solar equipment which may become available in the next decade, it also is extremely difficult to establish the cost of conventional energy systems which may be operating during the next few decades. The price of electricity, oil, and gas from conventional sources may change rapidly during the next few years, and the performance of equipment designed to consume energy from these sources may change dramatically as a result. Estimates of the future price of oil, gas, and electricity vary greatly. And no estimate is certain because of such imponderable as the rate of future oil discoveries here and abroad, the stringency of environmental controls, and political decisions made by international energy suppliers. Given the uncertainties about such a critical variable, it was necessary to compare costs using several different forecasts. The three forecasts used for most of the comparisons in this paper are summarized in tables I I-l and 11-2. They include assumptions that:

–The cost of electricity and fossil fuels will increase at the pace of general inflation (5. s percent in this analysis). (This is called "projection (1).")

Table 11-1.—Assumed Residential Fossil Fuel Prices in the Year 2000 (1976 $/kWhJ

	Projection (l)*	Projection (2)	Projection (3)
Natural gas			
Albuquerque	0.0050	0.011	0.016
Boston. ... ,	0.011	0.024	0.036
Ft. Worth	0.0050	0.011	0.016
Omaha	0.0037	0.0082	0.012
#2 Heating oil			
Albuquerque	0.010	0.014	0.033
Boston	0.010	0.015	0.034
Ft. Worth	N,A.	N.A.	N.A.
Omaha	0.0096	0.013	0.031

. Actual 1976 rates N A = not available

NOTE A fuel price of $001/kWh corresponds to an average monthly fuel bill of about $40/month for a single family house in Albuquerque using fuel for hot water and heating

Table n-2.-Typical Assumed Nonsolar Electricity Rates in the Year 2000 (1976 $/kWh$_e$)

	Projection (1)*	Projection (2)	Projection (3)
Albuquerque			
SF	.0244	.0354	.0802
HR/SC	.0207	.0300	.0680
Boston			
SF	.0440	.0638	.1445
HR/SC	.0557	.0808	.1830
Ft. Worth			
SF	.0269	,0390	.0884
HR/SC	.0294	.0426	.0966
Omaha			
SF	.0248	.0360	.0815
HR/SC	.0217	.0315	.0713

*Actual 1976 rates.

NOTES These average values are representative of the more elaborate electric rates! ruct ure actually used in the computer model

The model used actual utility rates in the region including demand charges and declining block rates when these features applied in the region

SF = prices charged for single family houses using electric heating

HR/SC = average rates charged for high rise apartments and shopping centers Demand charges are included, based on the estimated peak demands of the buildings in each city

An electricity price of $0 02/kWh corresponds to an average electric bill of about $70/month for an all electric house in Albuquerque

- Energy prices will rise at rates predicted by a Brookhaven National Laboratory (BNL) study. Electricity prices are expected to rise by about 41 percent (in constant dollars) by the year 2000 (to roughly the current marginal cost of electricity from new plants) and gas prices to increase by 123 percent during the same interval. (This is called "projection (2).")

—Energy prices will increase by a factor of 3.4 by the year 2000. Under this assumption, the price of oil and gas in most cities would be roughly equal to the price of synthetic fuels. Electricity rates would increase to $0.07 to $0.10/kWh in all cities examined except Boston, where the price would be somewhat higher. *

SUMMARY OF SYSTEM COSTS FOR CONVENTIONAL BUILDINGS

The increases in energy prices already experienced, and anticipation of further increases, have accelerated the development of efficient energy-consuming equipment. In almost all of the cases examined, investments in these energy-conserving devices were more profitable than investments in solar energy equipment, and it is always preferable to make a careful assessment of options for conserving energy before designing solar equipment for a building. Careful control of energy consumption will, of course, reduce the cost of the solar equipment required to meet the remaining load.

The cost of providing energy to single family homes in Albuquerque and Omaha which use different kinds of energy equipment are compared in tables I I-3 and I I-4. In all cases, the costs were computed for the years 1985-2015. (Most of the original equipment is replaced during this period, some of it twice; all of these replacement costs are evaluated in the analysis.) The numbers shown in the tables are the "levelized present value" of monthly energy bills. This "levelized" payment is defined to be the monthly payment which, if made regularly for 30 years, would result in the same present value, from the customer's perspective, as the actual expenditures. The actual expenditures will, of course, vary from year to year. The average monthly payments were displayed because most consumers find estimates of monthly energy payments easier to grasp intuitively. It should be noticed, however, that the average payments are some what above those now made in the cities involved, since the levelized costs shown reflect inflation occurring during the period when the system is operating.

Table II-3 shows the levelized monthly energy payments for houses equipped with several different kinds of gas furnaces, electric heaters, and heat pumps now on the market. The table also indicates the payments which would result if the performance of the equipment is improved. Oil and gas furnace efficiencies can be increased with careful design of the burners and by reducing flue temperatures. Hot-water heaters can be made more efficient by adding insulation. The table shows that investments in these improvements are attractive, even if the price of energy remains at 1976 levels (projection (1)).

While the heat-pump systems are less expensive to operate than electric-resistance systems, the benefits of the energy-saving, heat-pump systems are smaller than expected when a careful life-cycle cost analysis is used. This is because the heat pumps are more expensive to purchase initially and the expensive compressor elements of heat pumps typicaliy are replaced every 8 to 10 years. (Analysis in chapter V shows that the comparisons are even less favorable to heat pumps when the real cost of providing power to baseboard and heat-pump systems from conventional electric utilities is com-

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'All energy prices cited here and elsewhere in the report are given in 1976 dol lars

Table II-3.—Levelized Monthly Energy Costs for Single Family Houses Not Using Solar Energy*

Standard houses* •		Energy projection* •• (1)	(2)	(3)
Gas furnace, gas hot water, central electric a/c	A	116	173	287
	O	125	180	302
Gas furnace and hot water with improved efficiency, central electric a/c	A	111	160	265
	O	121	169	284
Gas heat, hot water, gas absorption a/c	A	122	187	295
	O	127	188	297
Oil furnace and hot water, central electric a/c	A	179	230	458
	O	204	263	522
Oil furnace and hot water with improved efficiency, central elec. tric a/c	A	163	208	406
	O	186	237	461
Baseboard-resistance heat, electric hot water, window a/c	A	177	238	490
	O	206	277	570
Electric heat pump and electric hot water	A	156	203	395
	O	190	249	490
Improved electric heat pump, electric hot water	A	146-162	187-203	353-367
	O	173	223	424

“System operates from 1985.2015

• •3 !iz.inch.fiberglass Insulation in walls, 6 inches in ceiling

“‘ “See table II-1

A = Albuquerque O = Omaha

puted – the tables reflect electric rates now charged in the regions.) The performance of heat pumps can be increased by developing better compressors, using multiple compressors, and with other techniques. These improvements can make the heat pump systems more attractive if the cost of the improvements is low, A 50-percent improvement i n heat pump performance is economic if it increases heat pump cost by 20 percent, but may not be if the cost increase is 80 percent.

Table I I-4 indicates the levelized monthly costs which result from adding extra insulation and storm windows and doors to the houses examined in table 11-3. It can be seen that this investment is attractive even if energy prices do not increase in real terms.

Table I I-4 also shows the costs which could be expected from a system that provides all energy needs, including electricity, by burning natural gas. This is a “total-energy” system using a gas-fired heat pump to provide heating and cooling; the engine

Table II-4.—Levelized Monthly Energy Costs for Single Family Houses With Extra Insulation*

		Energy price project ion •• (1)	(2)	(3) With 20-percent ITC on energy conservation equipment
Gas furnace, gas hot water, central electric a/c	A	106	153	254
	O	111	154	261
Oil furnace and hot water, central electric a/c	A	153	195	380
	O	163	208	402
Baseboard-resistance heat, electric hot water, window a/c	A	149	198	399
	o	159	211	423
Heat pump and electric hot water	A	142	183	350
	0	161	208	399
Gas heat pump and on-site electric generator (using **waste** heat)	A	113	146	173
	O	106	133	157

“System operates from 1985-2015 6-inch fiberglass insulation in walls, 12 inches in ceiling, storm windows, and doors

. ● See table II-1

A = Albuquerque O . Omaha ITC = Investment tax credit.

used to operate the heat pump compressor is also used to generate electricity. Waste heat from the engine’s cooling system is used to supply hot water and supplement the heating system. The cost of operating such a system is expected to be very close to the cost of operating an all-electric house.

Table II-5.—Levelized Monthly Energy Costs Per Unit in a 196-Unit High Rise Apartment*

		Energy price projection* • (1)	(2)	(3) With 20-percent ITC on energy conservation equipment
Gas heat, gas hot water, central electric a/c	A	51	71	129
	O	57	76	129
Central electric chiller, fan-coil electric-resistance heaters in each unit, electric-resistance hot water	A	84	113	232
	O	87	113	223
Oil-burning diesel-engine total energy system, using an organic Rankine device as bottoming cycle	A	78	99	108
	O	74	91	101

•System operates from 1985-2015 “ “See table II-1

A = Albuquerque O . Omaha ITC = Investment tax credit

Table 1 I-5 compares the levelized monthly costs borne by the tenants of a high rise apartment, assuming that all energy equipment was financed with the rest of the building. It is assumed that capital costs are simply included in the building rent. The advanced system shown in this case assumes the use of a diesel engine, total-energy system, which provides all needed heating, cooling, hot water, and electricity. Heat is received from the engine by placing a boiler in the exhaust of the diesel. Some of this thermal energy is used to operate a low-temperature heat engine when electric demands are high.

TECHNOLOGY OVERVIEW

PASSIVE SOLAR ENERGY SYSTEMS

The techniques just described for conserving energy in buildings can be supplemented by carefully designing buildings to: (1) maximize the amount of solar energy absorbed during winter and (2) minimize the heat absorbed and maximize natural convective cooling during the summer. Such techniques, which have come to be called "passive" solar systems, are principally skillful architecture and landscaping; many of the most attractive techniques were in widespread use in building designs before low-cost energy sources created a situation where buildings were designed without attention to energy consumption.

Energy requirements can be reduced by paying careful attention to the orientation of a building on its lot, the location of trees, the use of awnings or overhangs which permit sunlight to enter a room during the winter but shade the window during the summer cooling season, and other basic architectural features. Window size and location are particularly important. Large south-facing windows can provide over sO percent of the heating requirements of a room, even in climates with severe winters. Some passive buildings have covered the southern face of the house with a greenhouse. The performance of such systems can be improved by using thick walls and floors to store heat in the building's interior and by using movable insulation, such as shutters which can be adjusted to reflect outside heat or preserve heat in the building interior as needed. Carefully designed interior ventilation can amplify the heating and cooling available from such systems.

These systems may well be able to provide space-conditioning at a price comparable with or lower than the price of solar energy from the active systems examined in greater detail in the remainder of this chapter. It is often difficult, however, to determine the real incremental cost of passive solar equipment. (For example, how does one account for the fact that the addition of a greenhouse may make a building a more pleasant place to live?) While passive systems are usually extremely simple, and the principle of operation easily understood, analysis of their performance is only beginning. This study did not attempt to perform a detailed examination of these systems.

ACTIVE SOLAR SYSTEMS

A Survey of Components

Active solar systems require components which are distinct from the basic building structure. The systems consist of three basic elements:

1. A solar collector exposed directly to the Sun which converts light into a heated fluid or, in the case of solar cells, converts light directly into electricity.

2. An energy-storage system which stores excess energy available during sunny periods for use when direct sunlight is not available.
3. An energy-conversion system which converts the heated fluids into mechanical energy or electricity through a generator using a turbine or piston engine.

Not all solar systems will use storage or energy-conversion equipment.

SOLAR COLLECTORS

The design of attractive, reliable, low-cost collector systems is critical to the future of solar energy since the bulk of the cost of solar systems usually is attributable to the collectors and they are often highly visible. The collectors must cover areas large enough to collect the solar energy required, and these areas can be substantial since, at its peak, sunlight provides only about 1 kilowatt (kW) per square meter. The actual output of a square meter of collector, however, is much less than 1 kW. A typical photovoltaic collector can convert only about 10 percent of the incident sunlight energy into electricity, and the average intensity of sunlight (averaged over all hours of the year – day and night) is typically about one-fifth of the peak solar intensity. As a result, about 50 square meters (540 square feet) of these collectors (connected to an appropriate storage device) are needed to provide a continuous kilowatt of solar electricity. (A continuous kilowatt would keep ten 100-watt light bulbs burning.) Providing this continuous kilowatt, therefore, means that so square meters of some kind of material must be supported and made secure against adverse weather. Thermal collectors, used to provide hot water for heating or other purposes, typically are 2 to 4 times as efficient as the photovoltaic systems just described and require a proportionally smaller area to provide a continuous kilowatt of thermal output.

Two types of collectors are now on the market: nontracking collectors and collectors that follow or track the Sun during the day. Nontracking or flat-plate collectors have no mirror surfaces or moving parts and thus have the advantage of simplicity and reliability. They can be integrated into most architectural styles without being obtrusive. Flat-plate systems can capture “diffuse” sunlight (light reflected from the ground or the clouds), which most focusing collector systems cannot do.

Concentrating collectors that track the Sun can generate much higher temperatures than flat-plate collectors and therefore are more valuable for systems that use heat engines or for some types of industrial processes. They also can provide somewhat more output than flat plates. Few tracking collectors are now on the market, and most are relatively expensive. The potential for savings in production costs is large because they can use thin reflecting surfaces or plastic lenses over most of the area covered. Whether the cost of maintaining the equipment required to keep them pointed toward the Sun offsets the increased output is not now known and cannot be determined without operating experience. Collector alternatives are discussed in greater detail in chapter VII I.

SOLAR ELECTRIC SYSTEMS

Electricity can be generated directly from sunlight in two ways: (1) by heating fluids to operate heat engines (such as steam turbines) that turn electric generators; and (2) by using photovoltaic cells (solar cells) that are solid-state devices made from the same basic materials as transistors. Both approaches can be used to produce electricity alone or to provide both electricity and heat in a “total energy” or “cogeneration” system.

Heat Engines

Heat engines operate by taking a high-temperature fluid (which may be steam or a heated gas) and converting some of the fluid’s energy into mechanical power or electricity, cooling the fluid in the process.

The fluid which emerges from the engines can still be quite hot, however, and can be used for space-heating or other applications.

A number of heat engine designs eventually may be used in solar installations, but the small engines now on the market which are compatible with solar energy applications are quite expensive. Small gas and diesel engines cannot be easily used in solar systems since they require heat applied inside a cylinder; most engines designed for solar applications must be able to operate from heat applied to some external surface (e.g., to the boiler of a steam turbine).

Technology is available, however, for designing engines capable of operating from many different kinds of solar-heated fluids. The most straightforward approach is to use a solar collector to produce steam (typically at temperatures between 4000 and 1,0000 F) and use this steam in standard steam turbines or piston engines. The engineering of large steam turbines (100 megawatt and larger) is very advanced, and efficiencies above 40 percent are possible with high-temperature steam. Much less work has been done on smaller steam engines in recent years, however, and designs tend to be somewhat archaic.

The use of steam, of course, means that a high-performance tracking-collector system must be used, and a storage device must be developed which is capable of holding high-temperature thermal energy. It is possible to use much simpler collectors and storage devices with engines designed to operate at lower temperatures. Water is not a desirable working fluid at temperatures below 4000 F (and may not be desirable at temperatures below about 8000 F). Engines analogous to steam engines have been designed which are able to operate from fluids at temperatures as low as 1300 to 1800 F. These engines use freons (similar to the fluid used in refrigerators) or other organic fluids instead of water. The low-temperature systems can be extremely reliable (they are essentially refrigerators working backwards), but their efficiency is low (less than 10 percent if fluids of 1500 F are used), and contemporary devices tend to be bulky and expensive in small sizes.

A number of heat-engine designs also are available which are able to operate at the opposite extreme of temperatures. Brayton-cycle devices, similar to the gas turbines used in aircraft engines, may be practical if collectors can be developed which are capable of producing temperatures of 1,4000 For more at reasonable cost. Such systems will require the use of heliostat fields or other two-axis collectors. Relatively little work has been done on small, high-efficiency, Brayton-cycle devices, however, although several concepts are being pursued in connection with research on gas-powered heat pumps.

Small engines based on the Stirling or the Ericsson cycle may eventually prove to be the most attractive devices if high temperatures are available. These engines may be able to achieve efficiencies as high as 50 to 60 percent at relatively modest cost, but much more development work is required before reliable systems will appear on the market, It is unlikely that any engines based on these two cycles will be available commercially for several years, and they will be quite expensive unless mass produced.

In addition to the systems just described, a large variety of devices capable of converting thermal energy to electrical and mechanical power are in early stages of development. Chapter IX discusses engine cycles in greater detail.

Photovoltaic Systems

Photovoltaic devices, similar to the "solar cells" used to provide power for spacecraft, can convert sunlight directly into electricity with no moving parts. As a result, they can be extremely reliable and quiet. The cells are not as efficient as the best heat engines, but they can compete in efficiency with heat engines at lower temperatures (i. e., 4000 to 5000 F or lower). The main disadvantage of the photovoltaic technology at present is its extremely high cost. While inexpensive heat engines may cost as little as $100 to $200 per kilowatt, photovoltaic systems currently sell for approximately $11,000 per kilowatt. (The photovoltaic systems can provide this peak output only in bright sunlight,) Current Federal research programs have as their goal a cost for photovoltaic arrays of $2,000 per kilowatt by 1982 and $500 per kilowatt by 1986 (in 1975 dollars). Photovoltaic systems are discussed in detail in chapter X,

There are four basic approaches to achieving a cost reduction for solar cells:

1. Reducing the cost of manufacturing silicon cells, which are the most common photovoltaic devices This requires developing mass-production techniques to replace the inefficient processes now used to fabricate cell arrays, and it will require developing inexpensive techniques for producing and slicing silicon crystals. Silicon is an attractive material because it is plentiful and nontoxic.
2. Developing cells based on "thin films" of materials, such as cadmium sulfide or amorphous silicon, which can be applied directly to glass or other supporting material at very low cost. The main difficulty with the present thin film cells is their relatively low efficiencies. Low efficiencies mean that relatively large areas are required, and the cost of supporting these large areas of cells may exceed the cost of the cells themselves Competitive thin film cells probably will require efficiencies greater than 10 percent.
3. Using concentrating collectors to focus sunlight on photovoltaic cells, thereby reducing the area of cells required for a given energy output. A number of cell designs are being developed which are able to operate in a wide range of solar intensities. Some of these designs are variants of silicon designs, while others are based on gallium arsenide or other materials, The use of concentrating collectors replaces the problem of reducing cell costs with the mechanical problem of designing a focusing collector which can be manufactured at low cost. One feature of the concentrating systems is that it may be economically attractive to cool the cells with a fluid and use the heated flu id for space-heating or other processes, thereby taking maximum advantage of the investment in the collector.
4. Using properly designed sheets of plastic or glass imbedded with a fluorescent dye to concentrate sunlight reaching the face of the sheet on the thin edge of the sheet. (Anyone holding a sheet or rod of clear plastic may have noticed how the edge or end sometimes seems to glow.) The use of such a concentrator would eliminate the need to develop a low-cost focusing and tracking system, but there would be a need to find a low-cost dye with the proper optical properties capable of surviving bright sunlight for many years.

During the last few years, a number of techniques have been proposed for using photochemistry to generate hydrogen and other chemicals directly in solar collectors with chemical reactors driven by sunlight, The chemicals produced could then be stored or burned much like natural gas. Several preliminary tests have demonstrated the feasibility of the approach, although the efficiency of current processes is quite low,

ENERGY STORAGE AND BACKUP

The real cost of solar energy technology cannot be evaluated without considering the cost of energy supplied when direct sunlight is not available. The optimum process for maintaining energy availability depends on the relationsip between onsite users and existing utilities and on the eventual cost and performance of various storage technologies. Three basic approaches are possible for providing energy in an onsite solar system during periods when direct solar energy is not available:

- Energy can be generated by using fuel at an onsite facility.

— Electricity can be purchased from electric utilities for backup (and possibly sold to utilities when the output of onsite devices exceeds local demand).

— Energy can be stored in onsite storage devices.

There are several approaches to storing energy at a given site: fluids produced by thermal collectors can be stored directly, for example, and electricity generated by onsite systems can be stored in batteries or other electrical storage systems. It may be desirable to transmit thermal energy, electricity, or chemicals generated in onsite devices to central or regional storage facilities.

The lowest cost systems now available for storing thermal energy at low temperatures (below 2500 F) are simple hot water tanks or bins of heated rocks. These systems are so inexpensive that it will be difficult to find competitive alternatives, Present storage costs in such devices range from *$0.50* to $5 per kilowatt-hour of capacity of the device. Some advanced concepts for storing large amounts of low-temperature energy in underground caverns, aquifers, or porous rock could reduce this cost to $0.10 per kilowatt-hour or less, The somewhat lower efficiency of these large storage systems partially offsets the advantage offered by their low initial cost.

The price advantage of low-temperature storage may make it desirable to store energy during the summer for use during the winter.

High-temperature thermal storage is more expensive. Some types of oil can be used to store energy at temperatures up to about 6000 F for $2 to $5 per kilowatt-hour. Storage at higher temperatures (1 ,4000 to 1,6000 F) costs $3o to $5o per kilowatt-hour.

Electric storage is another option. The only electricity storage systems now commonly used by electric utilities employ hydroelectric facilities, in which water is pumped into an elevated reservoir when demand is low and released to generate electricity when demand is high. Other storage techniques in various stages of development include advanced batteries, flywheels, magnetic storage rings, and compressed air in underground caverns. The only electric-storage systems which are likely to be compatible with onsite solar systems in the near future will use some kind of battery.

The choice between storing energy and providing backup energy from some other source is very sensitive to the cost of storage and fuels. I n many cases, it is more attractive to burn even an expensive fuel for a few hundred hours during the year than it is to provide all backup requirements from onsite storage. Storage equipment is examined in detail in chapter XI, and the cost of different kinds of backup is discussed in detail in chapter V.

SUMMARY OF COST COMPARISONS

SOLAR HEATING AND HOT WATER

Although installations in four cities were examined in detail, this chapter presents only the results from Omaha and Albuquerque. Omaha was the least favorable location for solar energy systems of any of the cities examined in the study because it receives only average amounts of sunlight and utility electricity and natural gas prices there are relatively low. Albuquerque receives nearly 40 percent more sunlight, but, like Omaha, is below average in rates charged for energy from nonsolar energy sources. Moving from city to city, it is important to notice there is greater variation in the price of electricity than in the amount of sunlight available. Because of this, solar energy is nearly as competitive in Boston (where there is relatively little sunshine but where energy prices are high) as in Albuquerque where the reverse is true.

Solar energy systems designed to provide domestic hot water and space-heating require little more than a simple flat-plate collector and a tank for storing the heated water. Since it is often not desirable to run tapwater through a collector, a “heat exchanger” is typically used to transfer thermal energy from the collectors to the water circulated to the house. Heat can be provided to the building interior by running the solar-heated water through radiators or by circulating the water through coils and blowing air over these coils and subsequently through standard ductwork.

Table II-6 shows the levelized monthly costs for solar systems designed to provide building heating and hot water in Albuquerque and Omaha. (The cost range reflects different estimates of the future price of flat-plate collectors; the higher costs correspond approximately to the price of some equipment which should soon be on the market for new installations. Retrofits will probably be more expensive)

The table also shows the percentage of the building’s total energy requirements met by solar energy. (Notice that this is not the fraction of the heating or hot water load met with solar energy, but the fraction of all energy consumed for heating, hot water, lighting, etc.) When electricity is displaced, the primary energy consumed to produce electricity from fossil fuels is computed.

It is clear that solar hot water systems compare favorably with conventional electric systems in both cities, even in cases where no increase in the real cost of energy is assumed, Solar space-heating systems are marginally competitive with the conventional heat-pump systems only if electricity prices rise as forecast by the Brook haven National Laboratory (BNL); they look extremely attractive if prices rise faster than the BNL estimate. The solar devices would, of course, appear more attractive in the case of BNL price forecasts if investment tax credits or other incentives are enacted.

Houses connected together with a thermal-piping system to a central “seasonal-

Table II-6.—Levelized Monthly Energy Costs for Solar Heating and Hot Water Systems*

		Energy price projection **				
		(1)	(2)	(2) With 20-percent ITC on solar equipment	(3) With 20-percent ITC on solar equipment	Percent **solar**
Single family houses						
House with electric heat pump and electric hot water (shown for reference)	A	156	203	203	395	0
	O	190	249	249	490	0
Solar hot water	A	141-147	176-182	174-179	316-321	28
	O	184-191	234-241	232-237	437-442	17
Solar heat and hot water	A	158-187	184-213	177-201	284-309	48
	O	201-227	245-271	237-260	416-438	29
Solar heat and hot water (300 houses connected to central ‘‘seasonal” thermal storage tank)	A	165-214	184-234	171-211	249-290	65
	O	215-299	237-321	217-285	307-375	76
High rise apartments (cost per unit)						
All-electric conventional systems (shown for reference)	A	83-84	112-113	112-113	229-232	0
	O	83-87	109-113	109-113	215-223	0
Solar hot water (all-electric backup)	A	84-87	110-114	109-112	218-220	19
	O	85-89	109-113	107-110	203-206	13
Solar heat and hot water (all-electric backup)	A	87-95	113-120	109-115	212-218	31
	O	91-104	111-123	105-114	186-196	26
Solar heat and hot water with seasonal thermal storage	A	57-85	69-97	66-84	116-134	53
	O	92-127	103-137	90-114	134-157	61

*System operates 1985-2015 . “See table II-1
A = Albuquerque O = Omaha ITC = Investment tax credit

storage” facility can be provided with 100 percent of their heat and hot water demands at prices not significantly higher than for isolated solar systems on individual residences. In fact, the seasonal system is less expensive in cases where energy prices are expected to increase sharply.

Table II-6 also indicates the costs of several heating and hot water systems designed for use in a high rise apartment. The roof area available on the building was not sufficient to support all of the collectors required by the heating system examined; it was necessary to erect racks over the parking lot for the building to provide the additional collector area required. Use of these racks, of course, added to the cost of the solar-heating system. It would be possible to design a high rise building with much more area for collectors, thereby reducing the cost of solar energy. However, a conventional building design was chosen for analysis so that the costs estimated would apply to a wider range of new and existing structures.

The table also shows the cost of systems capable of providing 100 percent of the heating and hot water needs of the high rise building. In this case, there was no need to connect several buildings to a common storage tank, since the tank for storing thermal energy for the apartment was large enough to achieve the required economies of scale. The tank used in the analysis was assumed to be a commercial steel or concrete tank buried under the parking lot. (There is more than enough room for such a tank under the parking lot assumed for the building.)

Table II-7 compares the cost of solar-heating systems backed up with oil and gas with the cost of conventionl energy sys-

Table n-7.-Solar Heating and Hot Water Systems for Single Family Houses Compared With Conventional Systems Based on Oil and Gas*

	Energy price projection ••				
	(1)	(2)	(2) With 20-percent ITC on solar equipment	(3) With 20-percent ITC on solar equipment	Percent solar
Natural gas used as a backup					
Albuquerque—					
Conventional gas system	116	173	173	287	0
Solar hot water system	121-127	167-173	165-170	268-273	16
Solar heating and hot water system	143-172	172-201	164-188	251-276	41
Omaha—					
Conventional gas system	125	180	180	302	0
Solar hot water system	135-142	185-191	182-188	298-303	10
Solar heating and hot water system	165-191	207-233	199-221	308-330	24
Heating oil used as a backup					
Albuquerque—					
Conventional oil heat	179	230	230	458	0
Solar hot water system	168-173	210-216	207-212	392-396	18
Solar heating and hot water system ($45m^2$)	165-194	193-222	185-209	302-326	45
Omaha—					
Conventional oil heat	204	263	263	522	0
Solar hot water system	202-209	254-261	252-257	480-486	11
Solar heating and hot water system ($40m^2$)	219-244	262-288	255-277	444-466	26

“System operates 1985-2015. ••See table II-1. ITC = Investment tax credit.
NOTE: In all cases, solar systems are backed up with the fuel used by the conventional system used as a reference

terns using these fuels. In Albuquerque, the solar devices will be competitive with both oil and gas, if prices rise along the BNL forecasts, and will be attractive in both cities, if prices rise more rapidly. An increase in gas prices which exceeds the price increases forecast by BN L is clearly possible.

SOLAR AIR-CONDITIONING

Three types of solar cooling were simulated with the computer model:

1. A solar-heated fluid can be used to replace the burner in an absorption air-conditioner similar to conventional air-conditioners operated by burning natural gas.
2. Solar-heated fluids can be used to operate a heat engine connected to the compressor of a standard air-conditioning unit
3. Photovoltaic devices can generate electricity which operates a conventional electric air-conditioner.

Typically, the first two types of solar-cooling systems require fluids at temperatures of 1800 to 3000 F and, as a result, require higher performance collectors than solar heating and hot water systems.

Table II-8 compares the cost of several different conventional and solar approaches to air-conditioning. The results are somewhat difficult to interpret. Solar heating and cooling systems backed up with gas compare favorably with conventional all-electric systems, if BNL price projections are assumed. The solar systems compare favorably with the all-gas conventional systems only if a rapid increase in gas prices is assumed. An investment tax credit for the solar systems, however, could eliminate the cost differences in some locations.

SOLAR ELECTRIC SYSTEMS USING PHOTOVOLTAICS

A simple photovoltaic system can consist of an array of cells connected with an "inverter" capable of converting the direct current produced by the cells into the 60-cycle alternating current which is compatible with electricity provided by electric utilities. (It is possible to use direct current for most lighting, electric stoves, electric heating, and other purposes with little or no modification in the equipment – but a building would need special wiring and switching to use direct current, and this possibility will not be examined in detail.) Onsite storage can be provided using batteries, but it is usually preferable to sell excess electricity to the electric utility rather than storing it onsite, Utility storage tends to be less expensive, and excess onsite energy is typically available during periods when there is a large demand for utility electricity and the excess

Table II-8.—Levelized Monthly Energy Costs for Solar Air-Conditioning and Heating*

		Energy price projection ••				
		(1)	(2)	(2) With 20-percent ITC on solar equipment	(3) With 20-percent ITC on solar equipment	Percent solar
Single family houses						
All-electric house with heat pump (for reference)	A O	156 190	203 249	203 249	395 490	0 0
House with gas heat, hot water, and absorption gas a/c (for reference)	A O	122 127	187 188	187 188	295 297	0 0
Solar heat and solar absorption air-conditioning (gas backup for heat, hot water, and a/c) ($64 m^2$)	A O	137-165 171-211	161-190 205-245	153-178 194-228	224-248 279-313	56 44

"System operates 1985-2015 " 'See table II-1

A = Albuquerque O = Omaha ITC = Investment tax credit

onsite electricity is particularly valuable to the utility.

As noted previously, a number of difficult legal, regulatory, and rate-setting problems will need to be overcome before onsite systems can be connected to utility grids in most areas. (There should be no prohibitive technical problems.) For the purposes of this chapter, it is assumed that electric utilities purchase power from single family residences at exactly half the rate charged by the utility for power and that utilities buy power from high rise apartment systems at a rate equal to 0.4 times the price the apartments pay for electricity.

Table II-9 examines a number of flat-plate photovoltaic devices which can be used on the roof of a single family house. It is assumed that a weathertight roof exists under the cell arrays, and that the roof needs no special reinforcement for mounting the arrays. (The General Electric Company has proposed using a photovoltaic array as a shingle and argues that the devices should be given a credit as a roofing material, but no such assumption is used in the calculation presented in the table.) It is assumed that backup electricity is purchased at actual commercial rates (including demand charges) and that utilities are willing to purchase electricity in excess of onsite demands at a rate equal to 50 percent of the price charged for electricity,

The analysis indicates that cells which meet Department of Energy cost goals ($0.50 per peak watt) will be able to compete with conventional systems, if electricity prices increase slightly faster than the

Table II-9.— Flat-Plate Photovoltaic Systems on Houses With Extra Insulation and Storm Windows*

		Energy price projection ••				
		(1)	(2)	(2) With 20-percent ITC on solar equipment	(3) With 20-percent ITC on solar equipment	Percent solar
All-electric house with heat pump (shown for reference)	A	142	183	183	350	0
	O	161	208	208	399	0
Air-cooled silicon arrays ($1/watt)	A	222	249	230	338	52
	O	248	284	265	409	36
Air-cooled silicon arrays ($0.50/watt)	A	170	197	187	294	52
	O	196	231	221	364	36
Air-cooled silicon arrays ($0.50/watt) and 20 kWh onsite batteries	A	190	215	202	303	45
	O	217	251	239	378	32
Air-cooled silicon arrays ($0.50/watt), and heat-engine backup (no electric connection)	A	157	177	164	182	74
	O	161	178	165	182	72
Air-cooled thin-film arrays (7.8-percent efficient, $0.30/watt)	A	148	180	175	306	29
	O	163	199	194	336	32
Air-cooled thin-film arrays (10-percent efficient, $0.10/watt)	A	132	162	159	281	38
	O†	150	183	180	317	37
Air-cooled thin-film arrays (10-percent efficient, $0.10/watt)	A	127	154	151	260	46
	O†	150	183	180	317	37
Air-cooled fluorescent dye concentrator	A	133	150	142	214	90
	O	165	191	181	285	75
Fluorescent dye concentrator, photovoltaic and thermal	A	124	133	123	160	100
	O	165	185	174	256	80

*System operates 19852015 ••See table II 1 †Use Improved heat pumps
A = Albuquerque O . Omaha ITC = Investment tax credit

projection (2) forecast and some kind of investment tax credit is given to the solar system; the solar systems would almost certainly be competitive with the marginal cost of electricity produced from new plants.

The development of 10-percent efficient thin-film arrays costing as little as $0.10 per peak watt would result in systems able to produce electricity at prices somewhat less than the silicon systems. The savings are partially offset by the added cost incurred in supporting and mounting the relatively large arrays of thin-film cells.

Development of an efficient fluorescent dye concentrator system would lead to very significant savings, and systems based on such designs would be able to provide a large fraction of the total energy requirements of buildings with arrays covering the southern roof. Such devices, of course, must be considered extremely speculative at present.

One of the cases examined in table II-9 assumes that the house has no connection to the electric utility grid. It has all of its backup power supplied by a gas-fired heat pump and generator. This system will be competitive with the all-electric systems, even if gas prices increase significantly faster than electricity prices.

Table I I-10 illustrates the cost of flat-plate systems used for apartment buildings. The cost of the electricity from these systems is somewhat higher than in the houses since special racks need to be constructed for supporting the arrays over parking lots. This places an added penalty on low-efficiency systems requiring large collector areas. The advantage of using the cells as a building material, avoiding the cost of supports, is clearly apparent by examining the next-to-last example shown in the table. In this instance, it is assumed that cells are used to cover the southern wall of the apartments. No credit is given for the weatherproofing achieved by the arrays, but the cost of mounting and installing the cells is not charged as a solar-system cost. It can be seen that this application is attractive even though the cells are not mounted at an angle which would maximize their output. The building chosen for analysis again is not well-suited to such applications, since its southern wall can only accommodate cells capable of providing 5 to 6 percent of the total energy needs of the building.

Table 11-11 compares the cost of energy from a variety of different photovoltaic systems mounted on concentrating, tracking arrays. It is assumed that the installed cost of two-axis tracking devices is approximately

Table 11-10.—Flat-Plate Photovoltaic Systems Mounted on the Roof and Over the Parking Lot of a 196-Unit High Rise Apartment .

		Energy price projection**				
		(1)	(2)	(2) With 20-percent ITC on solar equipment	(3) With 20-percent ITC on solar equipment	Percent solar
All-electric system (shown for reference)	A	83-84	112-113	112-113	229-232	0
	O	83-87	109-113	109-113	215-223	0
Air-cooled silicon arrays ($1/watt)	A	149	173	153	254	36
	O	131	153	137	225	19
Air-cooled silicon arrays ($0.50/watt)	A	115	140	129	229	36
	O	105	127	118	206	19
Air-cooled thin film (10-percent efficient, $0.10/watt) mounted vertically on southern wall of building	A	84	112	111	223	6.3
	O	83	108	107	207	4.9
Air-cooled thin film (10-percent efficient, $0.10/watt)	A	95	120	115	219	25
	O	91	113	109	201	15

*System operates 1985-2015. **See table II-1.
A = Albuquerque O = Omaha ITC = Investment tax credit

Table II.11 .—Photovoltaic Concentrator Systems on High Rise Apartments*

		Energy price projection ••				
		(1)	(2)	(2)With 20-percent ITC on solar equipment	(3)With 20-percent ITC on solar equipment	Percent solar
All-electric system (shown for reference)	A	83-84	112-113	112-113	229-232	0
	O	83-87	109-113	109-113	215-223	0
One-axis tracking unit with silicon cells (near term)	A	164	188	164	261	63
	O	154	170	147	213	41
Two-axis tracking unit with silicon cells, cogeneration (near term)	A	95	120	114	214	37
	O	109	125	113	178	42
Two-axis tracking unit with GaAs cells (low cost)	A	85	100	92	153	75
	O	99	104	88	108	82
Two-axis tracking unit with 40-percent efficient cell	A	103	123	113	192	100
	O	106	112	92	117	86
Two-axis tracking unit with 40-percent efficient cell, diesel total-energy system for backup	A	81	92	78	88	79
	O	76	87	75	85	72
Two-axis tracking unit with GaAs cells, 100-percent solar system with seasonal electric storage (low-cost iron-REDOX batteries) and no backup	A	114	114	92	92	100
	O	218	218	176	176	100

● System operates 1985-2015. •● See table 11-1.
A = Albuquerque O = Omaha ITC = Investment tax credit.

$16/ft.2 The cogeneration systems are somewhat more attractive than the flat-plate systems, even though the collectors are more expensive, because a much higher net efficiency is achieved from the collectors (both thermal and electrical energy is produced). In cogeneration applications, the very high efficiency cells do not show major advantages over the lower efficiency devices — they produce the wrong ratio of electric to thermal output for the building chosen for study and excess electricity is sold at a low rate.

Systems capable of providing electricity and 100 percent of the heating and hot water requirements of the building compare favorably with conventional systems in several cases. The system designed to provide 100 percent of the building's energy needs from the solar equipment is competitive only if electricity prices increase relatively rapidly. The 100-percent solar systems shown here must be considered rather speculative, however, since it has been assumed that electric storage costs only $11/kWh – a price which may be possible, if the advanced iron-REDOX battery is developed.

It must also be recognized that the economics of the 100-percent solar system probably could be improved considerably, if more care were taken to optimize the system —by examining the detailed tradeoffs between collector sizes and the size of thermal and electrical storage devices installed. Finally, the 100-percent solar systems require collector areas too large to fit on a typical high rise parking lot.

SOLAR ELECTRIC SYSTEMS USING HEAT ENGINES

Solar electric systems using heat engines tend to be somewhat more complex than photovoltaic systems and impose a more difficult set of design decisions. The high-temperature fluids produced by the collector systems can be stored for later use in the engine, the engines can have one or more stages, heat can be extracted from the engine at different temperatures to meet direct heating requirements, and this relatively low-temperature energy can be stored separately. The electricity produced by the engine generator can be stored in batteries or other onsite storage facilities. Hydrocarbon fuels can be burned to operate the engine when solar heat is not available.

Since it **seemed unlikely that single family homes would be equipped with high-temperature collectors or large tracking dishes, the only heat-engine system examined for these buildings involved the use of a one-axis tracking system capable of producing hot oil at** *4000* **F. Table II-12 indicates that such a system could be attractive only if electricity prices rise relatively rapidly.**

Several more ambitious systems were examined for use with high rise apartments and other building types. An organic Rankine-cycle system capable of meeting 100 percent of the energy requirements of the building appears attractive only if thermal-energy storage is very low in cost (less than $0.10/kWh) and electricity prices rise rapid-

Table II-12.—Heat-Engine Systems*

		Energy price projection* •				
		(1)	(2)	(2) With 20-percent ITC on solar equipment	(3)With 20-percent ITC on solar equipment	Percent solar
Systems designed for use on a well-insulated family house						
House with gas heat, hot water, and absorption air-conditioner (shown for reference)	A O	110 111	163 158	163 158	260 254	0 0
One-axis tracking system with organic Rankine engine, low-temperature thermal storage only (Albuquerque)	A	184	218	203	235	42
One-axis tracking system with high-temperature thermal storage	A O	183 244	203 276	185 251	203 280	68 33
Systems designed for use on a 196-unit high rise apartment						
All-electric system (shown for reference)	A O	83-84 83-87	112-113 109-113	112-113 109”113	229-232 215-223	0 0
Low-temperature organic Rankine engine with seasonal thermal storage (flat-plate or pond collectors), 100-percent solar	A O	130-179 205-220	130-179 205-220	102-141 149-177	102-141 149-177	100 100
High-temperature Rankine engine (one-axis tracking collectors), fuel backup	O	108	129	115	135	14
Stirling engine system on two-axis tracking collectors (32-percent efficient engine), fuel backup	A O	67 97	77 107	68 94	77 103	72 63
Stirling engine system on two-axis tracking collector (47-percent efficient engine), fuel backup	A O	56 83	67 92	62 81	72 89	67 67
Stirling engine seasonal storage (high-temperature storage, 47-percent efficient engine)	A O	140 217	140 217	107 166	107 166	100 100

“System operates 1985-2015. •“See table 11-1.

A = Albuquerque O = Omaha ITC = Investment tax credit.

ly. The Stirling engine systems probably are the most speculative heat-engine cycles shown here, but are potentially the most attractive. Their performance is roughly analogous to the high-performance photovoltaic systems shown in the previous table.

COMMUNITY ENERGY SYSTEMS

The next cases examined involve systems designed to meet the energy requirements of a residential community of 30,000 persons. The community examined is roughly square — about a mile on a side. The distribution of building types found in the community is summarized in table I 1-13. This table also indicates that about 0.5 km^2 of area is available for solar collectors on southern-facing roofs and parking facilities. Another 0.25 km^2 would be available if all roadways in the community could be covered with collectors. This combined area would be nearly enough to provide all of the energy needs of the community in Albuquerque if high performance engines were used. Lower performance devices and less sunny regions would require significantly more area than is available from the roofs and parking facilities, and roads and special areas would have to be set aside for collector fields. It would be possible to greatly decrease the energy demand in the community if a concerted energy conservation program were implemented.

Table 11-13.—Buildings in the Community of 30,000

	Number Of buildings	Typical area available on southern roofs (m^2)	Area available on roofs and parking lots (m^2)
Single family detached residences.	1,864	81,600	81,600
8-unit townhouses	232	75,800	150,000
36-unit low rise apartments. , ...	72	48,500	103,400
196-unit high rise apartments. , ...	20	20,000	103,000
Shopping center.	1	28,800	63,000
Total roof and parking lot area.	2,189	254,700	501,000
Total road surface. . . .			250,000
Total available surface			751,000

Ground area required for 100-percent solar system in Albuquerque

	Area needed (m^2)
Parabolic dishes/Stirling engines.	800,000-1,000,000
Photovoltaic concentrator system (two-axis tracking)	1,400,000-1,800,000
Pond collectors/ORCS engine. . . .	1,900,000-2,500,000

As in the previous cases, the different systems are compared on the basis of the charges made to the energy consumers in the community. Three "conventional" communities were selected for reference: (1) a community with a mixture of heating and cooling systems roughly in proportion to the mixture actually occurring in the area being examined; (2) a community in which all buildings are assumed to use electric resistance heating and electric air-conditioning; and (3) a community in which al I single family houses, townhouses, and low rise apartments use heat pumps.

The costs of providing energy to the community from a number of different solar- and conventional-energy systems are compared in tables 11-14 and I i-l 5. Results are shown assuming that the systems are owned and operated by either a municipal utility (which is able to finance the project from tax-exempt bonds) or a privately owned electric utility.

Two conventional cogeneration systems are examined:

1. A diesel-engine system burning gas and using an organic Rankine system operating from the heat in the diesel exhaust to increase the performance of the electric generation when electricity demands are high.
2. A steam cycle burning coal in which hot water is extracted for use in absorption air-conditioners and district heating.

In both cases, energy is distributed throughout the community in two ways — as

Table II-14.— Levelized Monthly Energy Costs Per Unit for a Community in Albuquerque, N. Mex. (Municipal and Private Utility Ownership)

		Energy prices increase to level shown by year 2000 (Gas prices in $/MMBtu; electricity in $/kWh)			
	Percent solar	Gas: $1.46 Elec: $0.0271 (No increase)	Gas: $3.18 Elec: $0.0388	Gas: $3.18 Elec: $0.0388 20-percent solar ITC	Gas: $4.77 Elec: $0.0884 20-percent solar ITC
1977 mixture of buildings	0	**90**	126	126	226
All-electric resistance heat	0	**130**	174	174	357
Heat pumps in most buildings	0	**125**	165	165	325
Diesel/ORCS (gas backup)	54.0	**127 (160)**	140 (173)	132 (164)	93 (225)
Coal steam cogeneration	41.7	**125 (165)**	136 (175)	126 (164)	57 (195)
Solar steam cogeneration	70.1	**150 (203)**	156 (208)	143 (192)	58 (208)
Solar steam total energy with fossil superheat (coal backup)	66.4	144 (193)	150 (199)	37 (184)	55 (202)
Solar Stirling (high efficiency, gas backup)	91.4	146 (196)	149 (198)	37 (184)	148 (195)
Solar Stirling (low efficiency, gas backup)	90.4	157 (207)	159 (210)	47 (195)	160 (207)
100-percent solar, low-temperature ORCS(60 °-170 °,200 °F)	100.0	207 (278)	207 (278)	89 (256)	189 (256)
100-percent solar, low-temperature ORCS (90°-180 °,200 °F)	100.0	252 (338)	252 (338)	230 (311)	230 (311)
100-percent solar, silicon concentrator	100.0	188 (255)	188 (255)	171 (235)	171 (235)
100-percent solar heating, cooling, and hot water, flat-plate collectors	67.0	157 (213)	166 (222)	153 (205)	191 (244)
100-percent solar heating, cooling, and hot water, flat-plate collectors	67.0	128 (172)	138 (181)	127 (168)	165 (207)
100-percent,solar hot water and heat-pond collectors	54.7	**140 (175)**	155 (191)	147 (181)	210 (244)
100-percent solar hot water and heat-pond collectors	54.7	**127 (158)**	143 (173)	135 (165)	199 (228)

( ) = Private utility ownership. ITC = Investment tax credit.

electricity and as thermal energy. Hot and cold fluids are sent to each building for space-conditioning.

The tables also show the costs of a number of solar systems analogous to those previously discussed for use in individual buildings. Two systems not previously discussed are

1 A system based on a heliostat field and a central receiver which can provide high-temperature steam to a standard steam turbine; and

2. A system which uses solar heaters to boil water and a coal boiler to increase the temperature of the steam to the "superheated" level, which results In the most efficient steam cycle.

No easy interpretation of the results is possible. It is apparent that most of the solar systems do not become attractive on a strictly economic basis unless the most gloomy forecast of the price of conventional energy is accepted. with a tax credit or with municipal utility financing, however,

Table 11-15.—Levelized Monthly Energy Costs Per Unit for a Community in Omaha, Nebr. (Municipal and Private Utility Ownership)

		Energy prices increase to level shown by year 2000 (Gas prices in $/MMBtu; electricity in $/kWh)			
	Percent solar	Gas: $1.10 Elec: $0.0229 (No increase)	Gas: $2.39 Elec: $0.0329	Gas: $2.39 Elec: $0.0329 20-percent solar ITC	Gas: $3.59 Elec: $0.0748 20-percent solar ITC
1977 mixture of buildings	0	**98**	**133**	133	**236**
All-electric resistance heat	0	**131**	**174**	174	**351**
Heat pumps widely used	0	**130**	**169**	169	**326**
Central oil heat, electric a/c, grid elec	34.9	127 (152)	**149 (174)**	144 (168)	**237 (261)**
Diesel/ORCS (gas backup)	55.8	134 (170)	**147 (183)**	138 (173)	**197 (232)**
Coal steam cogeneration	**45.5**	139 (183)	**150 (194)**	139 (181)	**173 (215)**
Solar steam cogeneration	**67.7**	188 (253)	**195 (260)**	178 (240)	**198 (260)**
Solar steam cogeneration (fossil superheat)	65.1	177 (238)	**184 (245)**	169 (227)	**191 (248)**
Solar Stirling (high efficiency, gas backup)	87.5	197 (264)	**200 (268)**	184 (248)	**200 (264)**
Solar Stirling (low efficiency, gas backup)	85.8	208 (276)	**212 (280)**	195 (260)	**214 (278)**
100-percent solar, low-temperature ORCS(60°-170°,200° F)	100.0	280 (371)	**280 (371)**	257 (343)	**257 (343)**
100-percent solar, low-temperature ORCS(90°-180°,200°F)	100.0	371 (495)	**371 (495)**	339 (456)	**339 (456)**
100-percent solar, silicon concentrator with minimum collector area	100.0	339 (460)	**339 (460)**	308 (423)	**308 (423)**
100-percent solar, silicon concentrator with extra collector, less battery	100.0	296 (403)	**296 (403)**	268 (370)	**268 (370)**
100-percent solar hot water and heat-pond collectors	60.1	174 (221)	**188 (236)**	177 (222)	**237 (282)**

( ) = Private utility ownership ITC = Investment tax credit.

a number of very large solar systems are able to compete with conventional utility costs in Albuquerque and are surprisingly close to the cost of the conventional cogeneration systems, As expected, the solar systems are somewhat less attractive in Omaha, where the solar energy resource is smaller,

Since the thermal distribution system adds considerably to the cost of all of the community cogeneration systems examined, it is possible that the community chosen for analysis is too large for an optimum solar community system. Much more analysis would be required, however, to determine the optimum size and density of a solar community,

INDUSTRIAL SYSTEMS

The final series of tables examines solar devices used to provide energy for a large industrial plant. It is assumed that the plant requires a constant input of 150 MW of thermal energy and 30 MW of electric energy throughout the year. The analysis assumes that the factory works on three shifts, but the solar equipment would be more attrac-

Table 11-16.—Assumed Conventional Energy Costs for Large Industrial Users, 1976 Dollars

		1976 rates, year 2000 rates, projection (1)	Year 2000 rates, energy cost, projection (2)	Year 2000 rates, energy cost, projection (3)
Electricity (\$/kWh$_e$	A	.01526	.02190	.0499
	O	.01704	.02445	.0557
Natural gas—mils/kWh$_t$ and (\$/bbl oil equiv.)	A	**2.696 (4.60)**	**5.869 (10.02)**	**8.811 (15.04)**
	O	**2.365 (4.04)**	**5.149 (8.79)**	**7.729 (13.19)**
Residual Fuel Oil No. 6—mils/kWh$_t$ and (\$/bbl)	A	6.335 (10.81)	8.856 (15.12)	20.703 (35.34)
	O	5.474 (9.34)	8.025 (13.70)	17.889 (30.53)
Coal —mils/kWh$_t$ and (\$/ton)	A	2.80 (20)	4.42 (31.55)	9.15 (65.36)

A = Albuquerque O . Omaha

tive if it were assumed that the factory was not operated during the night.

In general, it is more difficult for solar energy systems to compete with the price of fuels conventionally used by industry. (Industrial fuel prices are summarized in table 11-16.) Industries can use a wider variety of fuels than residential and commercial customers, and electricity is delivered to industry at "bulk rates" which are usually considerably lower than residential and commercial electric rates The low industrial rates are due principally to the fact that no distribution system is required, billing services are simplified, and large industrial loads tend to be more regular than commercial and residential loads.

The use of solar energy in the industrial and agricultural sectors also is hindered by the high cost of capital used for typical investments in industrial equipment. In many cases, industries need to finance a large fraction of their new plant investments with equity and expect high rates of return on the investments, Payback times of 1 to 3 years frequently are expected. Widespread industrial use of cogeneration facilities based on conventional fuels also makes it more difficult for solar energy to compete with conventional alternatives.

Three different techniques for financing industrial equipment were examined:

1. Financing from a conventional industry, assuming that 75 percent of the cost was corporate equity on which a 20-percent return after taxes is expected, and 25 percent financed with bonds;
2. Financing from a privately owned utility; and
3. Financing from a municipal utility (or from low-interest bonds available from some other source).

A variety of different direct solar devices can be used to generate hot water for food processing, textiles, washing, and other industrial and agricultural applications. The cost of operating these systems is compared with the cost of conventional industrial equipment in table 11-17. It can be seen that the least expensive devices are the solar ponds, which may cost as little as \$30/m^2. Energy from conventional flat-plate collectors in industrial applications costs more than energy from roof-mounted collectors, since field-mounted systems require foundations, mounting racks, and expensive piping networks,

Table II-17.—Industrial Direct Heat Systems* Levelized Monthly Cost (millions of dollars)

System type		Energy price projection**												
		(1) Equipment owner			(2) Equipment owner			(2) with 20-percent ITC on solar equipment Equipment owner			(3) with 20-percent ITC on solar equipment Equipment owner			
		Munic-ipal utility	Private utility	Industry	Munic-ipal utility	Private utility	Industry	Munic-ipal utility	Private utility	Industry	Munic-ipal utility	Private utility	Industry	Percent solar
Oil Systems														
Conventional	A	2.19		2.23	2.99		3.03	2.99		3.03	6.55		6.59	0
	O	2.05		2.09	2.80		2.84	2.80		2.84	6.13		6.17	0
Ambient-180°F hot water—pond collectors	A	1.78-2.35	1.93-2.55	2.28-3.02	2.28-3.00	2.43-3.20	2.78-3.66	2.24-2.94	2.38-3.13	2.68-3.54	4.39-5.79	4.54-5.98	4.84-6.38	18-35
	O	2.20-2.62	2.43-2.92	2.95-3.63	2.77-3.25	2.99-3.55	3.51-4.26	2.71-3.17	2.92-3.45	3.37-4.07	5.16-5.91	5.37-6.20	5.82-6.81	17-25
180° F hot water—flat-plate collectors	A	2.36-2.94	2.80-3.62	3.87-5.25	2.85-3.43	3.30-4.12	4.36-5.74	2.73-3.24	3.15-3.90	4.07-5.29	4.87-5.38	5.29-6.03	6.21-7.43	36
	O	3.15-4.06	3.84-5.13	5.49-7.66	3.72-4.63	4.41-5.70	6.06-8.23	3.53-4.34	4.19-5.36	5.61-7.53	6.02-6.82	6.67-7.84	8.09-10.0	24
350° F process heat—one-axis tracking collectors	A	2.50-3.49	2.84-4.24	3.66-6.01	3.08-4.06	3.42-4.81	4.24-6.58	3.00-3.86	3.31-4.57	4.02-6.09	5.54-6.35	5.86-7.05	6.57-8.58	25-27
	O	3.17-6.06	3.78-6.06	5.25-8.99	3.73-5.38	4.34-6.62	5.81-9.56	3.57-5.05	4.15-6.22	5.41-8.74	6.02-7.53	6.60-8.70	7.86-11.2	25
Gas Systems														
Conventional	A	1.30		1.34	2.24		2.28	2.24		2.28	3.86		3.90	0
	O	1.29		1.33	2.17		2.21	2.17		2.21	3.82		3.86	0
Ambient-180° F hot water—pond collectors	A	1.38-1.71	1.53-1.91	1.88-2.38	1.94-2.45	2.09-2.65	2.44-3.12	1.90-2.40	2.04-2.59	2.34-3.00	3.17-3.84	3.31-4.03	3.61-4.44	18-35
	O	1.75-2.06	1.97-2.36	2.49-3.08	2.38-2.78	2.61-3.08	3.13-3.79	2.33-2.70	2.54-2.99	2.99-3.60	3.76-4.21	3.97-4.50	4.42-5.11	17-25
180° F hot water—flat-plate collectors	A	1.96-2.54	2.41-3.23	3.47-4.85	2.51-3.09	2.96-3.78	4.02-5.40	2.40-2.91	2.82-3.56	3.74-4.96	3.66-4.17	4.08-4.82	5.00-6.22	36
	O	2.68-3.59	3.37-4.66	5.02-7.19	3.32-4.23	4.02-5.31	5.67-7.84	3.14-3.95	3.80-4.96	5.22-7.14	4.58-5.39	5.24-6.40	6.66-8.58	24
350° F process heat—one-axis tracking collectors	A	1.96-2.98	2.30-3.72	3.12-5.49	2.62-3.62	2.97-4.37	3.79-6.14	2.53-3.42	2.86-4.13	3.57-5.65	3.90-4.78	4.22-5.48	4.94-7.00	25-27
	O	2.71-4.34	3.32-5.59	4.79-8.52	3.35-4.99	3.96-6.23	5.43-9.17	3.19-4.66	3.77-5.83	5.03-8.35	4.62-6.10	5.20-7.27	6.46-9.79	25
Coal Systems														
Conventional	A	1.47		1.74	2.06		2.33	2.06		2.33	4.08		4.35	0
	O	1.54		1.81	2.15		2.43	2.15		2.43	4.29		4.56	0
Ambient-180° F hot water—pond collectors	A	1.54-1.87	1.74-2.13	2.27-2.78	1.93-2.36	2.14-2.62	2.67-3.27	1.90-2.31	2.10-2.56	2.58-3.14	3.35-4.04	3.55-4.29	4.03-4.87	18-35
	O	1.95-2.28	2.23-2.64	2.93-3.53	2.43-2.81	2.71-3.17	3.41-4.05	2.37-2.73	2.64-2.94	3.27-3.86	4.10-4.59	4.37-4.94	4.99-5.72	17-25
180° F hot water—flat-plate collectors	A	2.12-2.69	2.62-3.44	3.86-5.24	2.51-3.09	3.02-3.84	4.26-5.64	2.39-2.91	2.88-3.62	3.97-5.19	3.84-5.35	4.32-5.06	5.41-6.63	36
	O	2.88-3.79	3.64-4.93	5.46-7.64	3.37-4.28	4.12-5.41	5.95-8.12	3.18-3.99	3.90-5.07	5.50-7.42	4.92-5.73	5.64-6.81	7.24-9.16	24
350° F process heat—one-axis tracking collectors	A	2.12-3.13	2.52-3.94	3.52-5.89	2.57-3.58	2.97-4.38	3.97-6.33	2.48-3.38	2.86-4.14	3.75-5.84	4.09-4.96	4.47-5.73	5.36-7.43	25-27
	O	2.92-4.55	3.59-5.85	5.23-8.96	3.40-5.04	4.07-6.34	5.71-9.45	3.23-4.70	3.87-5.94	5.31-8.63	4.96-6.44	5.60-7.68	7.04-10.3	25

*Conventional systems provide 150 MW_{th} continuously from a fossil boiler and use 30 MW of utility electricity. Solar systems produce only thermal energy, use a fossil boiler for thermal backup, and use 30 MW of utility electricity.

**See table II-16.

A = Albuquerque O = Omaha

The table indicates that the pond systems should be able to produce hot water in Albuquerque at prices competitive with oil, even if oil prices do not increase. Solar heat in the less-favored Omaha climate would start to be competitive in 1985 only if oil prices are expected to increase to $14 to $16 per barrel by the year 2000. Virtually all of the solar hot water systems would be competitive by 1985, if the price of oil is assumed to increase to $30 to $35 per barrel by the year 2000. Municipal utility financing, or some other form of subsidized financing, would make it much easier for industrial solar-energy systems to compete.

If solar hot water systems are to compete with natural gas by 1985, it must be assumed that industrial gas prices will rise by more than a factor of three by the year 2000 (i. e., to the equivalent of $14 to $16/barrel of oil or more). Solar units should be able to compete with the heat generated by burning hydrocarbons made synthetically from coal, but would not be able to compete with direct combustion of coal by 1985— unless the price of coal increased to more than $60 per ton by the year 2000, a price increase which seems unlikely at present.

It must be emphasized that there were few applications where solar energy was competitive with conventional fuels, if the solar equipment was financed with conventional industrial-plant financing. The solar equipment was considered "competitive" if the levelized price, assuming private-utility financing, was equivalent to the levelized price of energy from conventional sources, Low- interest "municipal" utility financing lowers the fuel cost at which the solar systems become competitive.

About 5 percent of U.S. energy is consumed by agricultural and industrial processes at temperatures between 5500 and 2120 F (6.5 percent, if preheat energy is counted.) Relatively simple one-axis tracking Collectors can be used to provide process heat at temperatures as high as *5500* F *(288 'C)* Collectors for this purpose were assumed to cost $80 to $1 40/m ^{2}[not including installation) and, as a result, the solar energy provided at these temperatures costs about twice as much as the solar energy provided by pond collectors at temperatures below 2120 F. Table I 1-17 also indicates the cost of solar energy produced at 3500 F (177 "C). It can be seen that statements made about the competitiveness of direct solar hot water production can be applied to heat produced at this higher temperature, if it is assumed that fuel prices increase about twice as fast as assumed in the previous statements. Since even the low-cost tracking collectors examined cost more per pound than many types of manufactured products, it may well be possible to reduce solar costs below those shown here.

The cost of several different solar cogeneration systems is shown in table I 1-18. Solar cogeneration systems, using small heat engines or photovoltaic devices, may be competitive with conventional fossil systems in roughly the same conditions that solar hot-water systems were shown to be competitive. Presumably, this is because the cogeneration systems are able to provide relatively expensive electricity and more useful energy per unit of collector area.

Three types of solar systems were examined:

1. A two-axis tracking system using a thin plastic lens focusing light on a silicon photovoltaic cell (waste heat is assumed to be collected from each cell at 1800 F and piped to a central storage reservoir).
2 A two-axis tracking frame covered with an array of mirrors focusing on a Stirling engine (waste heat at *3500* F is collected with a piping system).
3 A steam system using a field of mirrors (heliostats) focusing light on a central tower (in this case, the waste heat at 3500 F is available at the tower site).

One difficulty encountered in reviewing the future value of solar-generated heat for industry is that as energy prices increase, industries undoubtedly will find many places where low-temperature heat can be recov-

Table II-18.—Industrial Cogeneration Systems* Levelized Month Cost (millions of dollars)

System type		Energy price projection**												Percent solar
		(1)			(2)			(2) with 20-percent ITC on solar equipment			(3) with 20-percent ITC on solar equipment			
		Equipment owner			Equipment owner			Equipment owner			Equipment owner			
		Municipal utility	Private utility	Industry	Municipal utility	Private utility	Industry	Municipal utility	Private utility	Industry	Municipal utility	Private utility	Industry	
Oil Systems														
Conventional oil boiler, utility electricity	A	2.19		2.23	2.99		3.03	2.99		3.03	6.55		6.59	0
	O	2.05		2.09	2.80		2.84	2.80		2.84	6.13		6.17	0
Oil-fired Stirling cogeneration	A	2.14		2.25	2.77		2.89	2.77		2.89	5.70		5.82	0
	O	1.90		2.02	2.45		2.57	2.45		2.57	4.98		5.10	0
Solar Stirling cogeneration oil backup	A	2.69	3.28	4.68	2.99	3.58	4.98	2.87	3.43	4.68	4.26	4.83	6.08	61
	O	3.62	4.56	6.82	3.91	4.86	7.12	3.69	4.59	6.58	5.05	5.95	7.93	56
Photovoltaic cogeneration, oil boiler and util elec backup	A	2.15-2.56	2.49-3.06	3.29-4.23	2.62-3.03	2.95-3.52	3.75-4.70	2.53-2.90	2.84-3.37	3.54-4.38	4.59-4.97	4.90-5.44	5.60-6.46	45-47
	O	2.69-3.30	3.30-4.38	4.76-6.56	3.08-3.86	3.68-4.78	5.15-6.96	2.91-3.62	3.49-4.48	4.75-6.36	4.97-5.37	5.19-6.24	6.45-8.11	49-52
Gas Systems														
Conventional gas boiler utility electricity	A	1.30		1.34	2.24		2.28	2.24		2.28	3.86		3.90	0
	O	1.29		1.33	2.17		2.21	2.17		2.21	3.82		3.86	0
Gas-fired Stirling cogeneration	A	1.13		1.25	1.92		2.04	1.92		2.04	2.65		2.77	0
	O	1.04		1.16	1.73		1.85	1.73		1.85	2.37		2.49	0
Solar Stirling cogeneration, gas backup	A	2.22	2.80	4.20	2.59	3.18	4.58	2.47	3.03	4.28	2.81	3.38	4.62	61
	O	3.16	4.11	6.36	3.53	4.48	6.73	3.31	4.21	6.20	3.65	4.55	6.54	56
Photovoltaic cogeneration, gas boiler and util elec backup	A	1.66-2.08	1.99-2.58	2.79-3.76	2.20-2.62	2.53-3.12	3.33-4.30	2.11-2.49	2.42-2.96	3.12-3.98	3.07-3.51	3.39-3.98	4.08-5.00	45-47
	O	2.29-3.08	2.90-4.00	4.37-6.28	2.74-3.54	3.35-4.46	4.82-6.64	2.58-3.30	3.16-4.17	4.42-6.04	3.40-4.22	3.98-5.08	5.24-6.96	49-52
Coal Systems														
Conventional coal boiler, utility electricity	A	1.47		1.74	2.06		2.33	2.06		2.33	4.08		4.35	0
	O	1.54		1.81	2.15		2.43	2.15		2.43	4.29		4.56	0
Coal steam cogeneration	A	1.32		1.79	1.80		2.27	1.80		2.27	3.25		3.72	0
Solar steam cogeneration, coal backup	A	2.16	2.75	4.24	2.41	3.00	4.49	2.28	2.85	4.18	3.04	3.61	4.94	61
	O	2.79	3.84	6.02	3.24	4.11	6.28	3.03	3.86	5.78	3.83	4.66	6.58	56
Photovoltaic cogeneration, coal boiler and util elec backup	A	1.81-2.23	2.20-2.79	3.18-4.15	2.16-2.59	2.55-3.14	3.53-4.50	2.07-2.46	2.44-2.99	3.31-4.18	3.26-3.70	3.63-4.23	4.50-5.42	45-47
	O	2.49-3.28	3.16-4.25	4.80-6.61	2.80-3.61	3.47-4.58	5.11-6.94	2.64-3.36	3.28-4.29	4.72-6.34	3.72-4.52	4.35-5.45	5.79-7.50	49-52

*All systems meet a continuous demand of 150 MW_{th} and 30 MW_e. Photovoltaic cogeneration systems supply process heat at 180° F, and all other solar systems provide process heat at 350° F.

**See table II-16.

A = Albuquerque O = Omaha

ered from existing manufacturing processes at relatively low cost, possibly narrowing the market for solar equipment Conventional cogeneration also will become increasingly attractive as fuel costs rise. Solar cogeneration systems were able to compete with conventional cogeneration systems used in industry In sunny regions only if It was assumed that oil prices increase to more than $1 6/-barrel by the year 2000 (the more expensive systems required prices near $30/bbl to compete) In less-favored climates, it was necessary to assume that oil prices rose to more than $20 to $25/barrel before solar compared favorably

It can be seen, therefore, that while a market for solar heat and electricity for industry may develop by the mid- to late-l 980's, the major near-term use of solar energy in these applications is likely to occur in situations where conventional fuels are not readily available or inconvenient to use, or where increased use of these fuels is forbidden by national standards for air and water quality,