I was asked to summarize the current status of solar heating and cooling and to make some predictions of future developments. My approach is from two points of view, the research and development end and the commercial end, in both of which I am involved. To gain perspective on the present status and future prospects, we should first look at the past.

Solar space heating started only about 35 years ago. Prior to that time we had commercially applied solar energy only to heating the domestic water supply in very mild climates. Solar water heaters have been in use for almost a century, but their first application to heating buildings was in 1938. I shall introduce solar space heating by first discussing solar water heaters because the technology is similar.

Thousands of solar water heaters were used in Miami 30 years ago before natural gas was piped into the city. A small glass-covered panel on the house roof contains an array of pipes through which water, circulated naturally by gravity, is heated by the sun (Figure 1). The warmed water flows to the white insulated tank on the roof ridge (which looks like a chimney) and which contains enough water for the average family. On a large house, (Figure 2), two solar water heaters and two storage tanks were sometimes used. Such units were common in Miami during those years. They gradually went out of use when natural gas arrived, because maintenance was often required, and the cost of a conventional heater was moderate. Solar water heating is now reviving, and in some other countries, it is widely used.
The countries in which solar water heating has continued to be commercially important are Japan, Australia, and Israel (Figures 3 and 4). They are used particularly in rural areas where gas and electricity may not be centrally supplied.

Moving from a solar water heater to a solar space heater is primarily a matter of system size. The first buildings in America to be heated by solar energy were at MIT in the early 1940's. An experimental house (Figure 5) was provided with a large solar heater which supplied hot water to a tank in the attic space. Heat was delivered to the building when required; fuel was used for heating when solar was insufficient. Performance was carefully evaluated and an improved system was installed in a house in Lexington, Massachusetts in the mid-1950's, (Figure 6). A solar collector provided hot water to a heat storage tank in the basement, and an oil-fired furnace supplied the auxiliary heat. The solar system contributed about 60 per cent of the heat requirements of this house. Part of the domestic hot water supply was also furnished by heat exchange with the solar storage.

At a laboratory at the University of Arizona in Tucson a different concept was tested in the 1950's (Figure 7). An unglazed, bare metal solar collector supplied warm water to a storage tank from which a heat pump extracted heat for delivery at higher temperature to water circulated through a heating panel in the ceiling of the laboratory. The collector was also used for dissipation of heat on summer nights by operating the heat pump in reverse to cool the building.

The U.S. has not had a monopoly on the solar heating field. A house in Capri (Figure 8) in southern Italy was heated by a solar water heater mounted vertically on the south wall. The heat captured in the liquid was stored in a tank as in most of the previously described systems.

A house in Japan, (Figure 9) has been solar heated for many years, by a heat pump system similar to that used in Tucson, Arizona. More recently, a
house and a commercial building in Japan were provided with solar heating and cooling systems (Figure 10 and 11). In a recently built house in Colorado Springs (Figure 12), a non-freezing organic liquid is heated in the solar collector, thereby avoiding one of the problems encountered in the operation of a solar liquid system in a freezing climate. Auxiliary energy is supplied by a heat pump.

All of the practical solar heating systems have involved auxiliary fuel use because only by such a mix of solar and fuel can an economical design be realized. It is totally impractical and uneconomical to design a solar system to carry the entire load. The major part of the load is usually met by solar and fuel or electricity supplies the balance.

Current research and development in solar heating and cooling are being conducted by numerous organizations in the United States. At Colorado State University one of the more important experiments involves the construction and operation of several types of solar heating and cooling systems. Data on performance and costs are being obtained so that comparisons between systems can be reliably made. There are three houses of identical design (Figure 13), each heated by a different type of solar system. The one on the left, built two years ago, is the first solar cooled house in America. It is also solar heated, and the domestic hot water is furnished by solar exchange. A liquid collection and storage system is used. The middle house is solar heated by an air system, and the domestic hot water is provided by exchange with air that is heated in the collector.

The third house is finished, and the solar equipment will be installed in the summer of 1976. The liquid collector will be an evacuated tubular type of advanced design.

CSU Solar House I has three thousand square feet of floor space on two levels. It is used as an office and laboratory building (Figure 14). It is operated at constant temperature just as a residence would be. The 750
square foot solar collector provides heated antifreeze solution to a heat exchanger in which heat is transferred to water for storage (Figure 15). This arrangement is used because the cost of freeze protection of the entire 1100 gallons of liquid in storage would be prohibitive. The collector pump and storage pump circulate the two fluids whenever the sun is shining and useful heat can be collected.

The storage tank supplies heat for three uses. It heats the domestic water supply by means of a heat exchanger, though which city water is circulated. When the house needs heat, warm water is drawn from storage to another heat exchanger through which the house air is being circulated. Warm air is delivered to the rooms and the water returns to the storage tank. If the stored water is not warm enough to meet the load, an auxiliary heater supplies hot water to the air heating coil so that there is sufficient heat to meet the most severe demand.

When cooling is required, hot water from the storage tank is used as the energy supply to a heat-operated air conditioner. This lithium bromide absorption refrigeration unit is a commercial product which can be operated with hot water at temperatures in the range of 180 to 200 degrees. When the water is at that temperature it is circulated to the air conditioner to provide cooling for the building; the water returns to storage. If the storage temperature is below 180 degrees, the auxiliary heater supplies hot water to the cooling unit. This system has been in operation for about a year and a half.

Typical winter performance of the system is shown in Figure 16. The vertical scale shows the amount of heat supplied each day to the house, in megajoules (approximately equivalent to thousands of Btu). The clear area represents the heat supplied from solar and the cross hatched area represents heat from fuel. No fuel was used until December 19, and after that date there were intermittent needs for the fuel supplement.
Figure 17 shows the use of solar energy and auxiliary fuel for domestic water heating in August. Energy requirements for cooling in August are shown in Figure 18, the shaded areas being the solar supply.

Solar and fuel use for the three purposes during a six-month period are shown in Figure 19. The second column of numbers shows the heating requirements of the house during this season, about 21 million Btu being supplied by solar and 3.3 million from fuel. So 86 per cent of the heating requirements were met by solar. For hot water, shown in the next column, 68 per cent of the energy came from solar. And for cooling, the next column shows that only 36 per cent of the energy needed was solar.

The design of the system was based on the supply of 75 per cent of heating and 75 per cent of cooling by solar energy. We met the heating objective, but we fell considerably short of the cooling forecast. But during this first month of operation, we were learning how to run the solar cooling system and trying to improve its performance. Some minor changes in design and operation increased the solar cooling fraction the following summer. We are continuing to improve performance and we hope eventually to meet the solar cooling design goal. Clearly, solar cooling is still highly experimental and not ready for public use.

There has been less said about air system than water systems, I think for the reason that solar space heating with hot water was a natural outgrowth of the domestic solar water heaters that had been in use for decades. It was necessary only to increase their size. The first solar air heating system was built on a Colorado house in 1944 (Figure 20). It was mounted on an existing house and supplied about a third of the heat requirements.
Heat storage in a liquid system is usually as hot water in an insulated tank. With air collection, the heat could be transferred to liquid and stored in the same way, but it is more efficient and much more cost-effective to store it in a bin of small rocks or "pebble-bed". Hot air from the collector is circulated through the mass of one-inch rocks, thus transferring heat to storage; house air is subsequently heated by circulating it through the pebbles.

The next air system was built into a Massachusetts house. It had vertical collectors on the south wall from which heated air was delivered (Figure 21). Heat storage was in a chemical known as Glaubers salt which melts when heated by warm air from the collector. Cans of this material, stacked in closets through which house air is then passed, supply heat as the salt recrystallizes. This system is more compact than the pebble-bed but is more expensive and not commercially available.

The oldest solar heated house in continuous use to the present is my Denver home built 19 years ago in 1957 (Figure 22). The solar heating system was installed in the house during its construction. Approximately one-fourth of the large heat requirements are met by solar, the balance by natural gas. There has been no maintenance on this system since it was built, and no cover glass breakage has occurred from any cause. Two views of the collector, one in 1958 (Figure 23), and the other in 1973 (Figure 24), show the durability of the system. Operation has been completely satisfactory and dependable.

The storage in this system is in the form of two fiberboard cylinders mounted in the stairwell of the house. They are filled with eleven tons of inch and a half gravel which store the heat that is supplied from the hot air coming from the collector (Figure 25). Two solar collector panels on the roof supply hot air through a duct to the basement. The air then passes through a heat exchanger, like an automobile radiator, in which the house hot water is being heated. The air continues on into the blower, up
through the furnace if the house needs heat, and through the distribution ducts to the rooms. Cold air returns from the rooms to the collector. When the rooms are warm enough, a thermostat shifts dampers which direct the air to the base of the heat storage bins so that the hot air passes up through the rocks, transfers its heat to them, and returns to the collectors. During most of the day, heat is being transferred from the solar collector to storage. When heat is needed at night or during cloudy weather, other dampers change their position and the blower draws house air down through the hot rocks and delivers that warm air to the rooms. If the air is not warm enough to satisfy the thermostat, the furnace goes on and increases the air temperature so that the demand can be met under all conditions.

There are 18 years of operating experience now available for guidance in commercial application of this system. Its performance in the 1959-1960 season has recently been compared with detailed data for the 1974-1975 season. After fifteen years of use, the system output was found to have decreased about 15 per cent, a very acceptable level. We have just completed some refurbishing of the collector. Next winter we shall determine whether the original performance has been regained.

Taking December as a typical winter month, the chart (Figure 26) shows that the house required about 29 million Btu of heat in that month. The unshaded bar is the total amount of solar energy, about 22 million Btu, that was intercepted by the collector. Solar energy that comes early in the morning and late in the afternoon isn't intense enough to be useful so the collector system is operated only during the time that about 15 million Btu fell on the collector. Of that quantity, we collected and delivered to the house about 7 million Btu. During the entire heating season, approximately one-fourth of the requirements for hot water and space heating were supplied by solar.
An interesting type of solar air system has been experimentally used in southern France for a few years (Figure 27). Solar energy passes through a double-glass surface and is absorbed on a vertical black concrete wall about a foot and a half thick. The temperature of the wall rises during the day as the energy is absorbed. Slots through the concrete wall at its base and top connect the living space to the air space between the wall and the two glass sheets. Air can then circulate from the rooms up through the space between the wall and the glass and back into the rooms. Natural draft, or a chimney effect, moves the air. No fans, dampers, or controls are used. If room overheating occurs, doors or windows can be opened. Rooms on the north side of the building must be heated by an auxiliary source. A solar air heater was combined with heat of fusion storage and photovoltaic cells for partial electrical supply in a house built two or three years ago by the University of Delaware (Figure 28).

The solar air heating system used for many years in the Denver house has now been in commercial production for about a year by the Solaron Corporation. The collector is applied to the subroof of a building as indicated in Figure 29. A layer of insulation reduces downward heat loss from the thin air passage. The top of this shallow air duct is coated with a black surface to absorb the radiation and covered with two layers of tempered glass in a hermetically sealed structure. Air is supplied to the collector at about 70 degrees, either from the rooms or from the cold end of the pebble-bed. It is heated typically to about 150 degrees and is supplied either to the rooms or to the hot end of the pebble-bed. In a complete system (Figure 30), there is a collector, two ducts between collector and storage, an air handler, controller, pebble-bed, and a conventional furnace assembly. In most houses, a pebble-bed having a roughly cubical shape is the most practical and economical design. Hot air from the collector is supplied to the pebble-bed, usually in the basement, from one of the ducts leading
from the collector (Figure 31). A typical residence is provided with 12 to 15 tons of gravel in a seven foot cube, which can store and furnish average overnight requirements. The air handler is a cabinet which houses motor and fan, automatic damper, and looks something like a conventional furnace. There are, accordingly, three components in the basement or other house area to supply space heating - storage, air handler, and furnace.

In a typical commercial air system in a residential installation, cold and hot air ducts pass through the attic space (Figure 32). Air is supplied from the cold air duct to the collector at three points, and two hot air outlets to take the hot air from the collector to a header which leads to the basement. An example of a retrofit installation (Figure 33) is a fifty year old house, provided with a new roof. The remodeling included a Solaron air system, the storage for which was placed in the original heat storage place - the coal bin.

A house in Boulder, Colorado is heated by a solar air collector on part of the south wall (Figure 34). A well designed collector can be substituted for the building surface. If the collector itself is water-tight, as is this one, it can replace siding or roofing.

A commercial building in Denver (Figure 35) is partially solar heated by the air system comprising a 1600 square foot collector on the flat roofed building and a pebble-bed in the work area. The solar unit supplies more than three-fourths of the total heat requirements of the office and show rooms.

A large house near Fort Collins, Colorado has a twelve hundred square foot Solaron collector which provides about three-fourths of the heat used in a house with about 3600 square feet of floor space (Figure 36).

The second solar house at Colorado State University is provided with a solar air system (Figure 37). It is now under test, and the performance will be compared with the liquid system in House I. This is an ideal opportunity
for system comparison because the two houses are the same size and design, in the same location, with identical weather and sunshine.

The third CSU house is going to have an advanced design experimental system. The collector, made by the Owens-Illinois Glass Company, is a set of glass tubes in which radiation absorbing surfaces are surrounded by an evacuated space in a manner similar to a thermos bottle. Heat loss is thus very low. Liquid enters a manifold, flows in series through the tubes, and leaves the array through a hot manifold (Figure 38). The efficiency of this collector is much higher than the conventional flat plate system, particularly when at the high temperature required for air conditioner operation. Heat storage and cold water storage will be used with this collector in CSU Solar House III.

Another type of evacuated tubular collector is made by the Corning Glass Works (Figure 39). It has a flat metal absorber plate inside a four-inch evacuated glass tube. Liquid enters at one end, flows around through a small metal tube affixed to the absorber plate, and leaves at the same end. A selective coating on the black plate minimizes radiation loss. An array of half a dozen manifolded evacuated tubes is shown in Figure 40. This collector will be installed as an alternate solar heat supply for CSU Solar House I. We will be able to switch back and forth between the conventional collector now on the roof, and this evacuated tubular collector which will be built on a ground-supported structure adjacent to the house. Following the studies on this system, a third type of evacuated tubular collector made by the Philips Company in Europe will be installed and tested.

Although there is essentially no doubt that evacuated tubular collectors are more efficient than the conventional types, costs are uncertain. It is Btu's per buck that is really the important criterion, so it is hoped that the present high cost of these evacuated tubular collectors can be reduced to the point where these units can challenge the conventional flat plate collectors now on the market.
On the subject of costs in general, solar heating is already competitive with electric heating in a number of localities. It is a proven technology and some durable, dependable equipment is on the market. The company with which I am associated has sold solar heating systems for about 75 buildings in completely commercial transactions without subsidies of any kind. Our experience with system costs and savings is thus of some consequence. Let us examine the economic factors by use of an example.

A good quality air collector costs about 10 dollars per square foot. A 500 square foot collector for a typical 3-bedroom house thus represents an outlay of $5000. A number of other costs now have to be added. There is the cost of the storage unit, the equipment to circulate the fluids, the controls, and the installation. In a liquid system, an insulated storage tank will cost at least a thousand dollars, and another thousand is needed for pumps, valves, and controls. Installation costs have been requiring 3000 to 4000 dollars, so the typical total installed cost of a liquid system is 10 to 12 thousand dollars. The cost of the air system marketed by Solaron appears to be moderately lower, but the difference is not large. Our residential hardware contracts range from 4 to 10 thousand dollars, depending on the systems size. Those prices include the collector, the air handling equipment and the controls, to which must be added the cost of the storage bin and the cost of installation. Typical total installed costs of the system are in the range of 8 to 10 thousand dollars today. Justification for that large expenditure lies in the size of the energy savings it effects. With electric heat at 4 cents per kilowatt-hour in some localities, and costs approaching 1500 dollars per year, a 75 per cent reduction by use of solar makes the 1200 dollar saving an attractive option. With that kind of saving, a ten thousand dollar investment can be well justified. Borrowing that total for 20 years at 8 per cent interest would require annual payments of about one thousand dollars, so an annual savings of 200 dollars would be realized in this example. At today's
prices, solar heating is not competitive with natural gas and fuel oil, but where electricity price exceeds 4 cents per kilowatt-hour, solar is a competitor in most places in the country. In sunny climates with long cold winters, solar is approximately the same cost as electricity at 3 cents a kilowatt-hour.

What of the future? The cost of solar heating systems will decrease, but not very much. The collector is composed of metals, glass, and insulation, materials already produced in enormous quantities. Their costs, in constant value dollars, are not going to decline. I don't foresee the costs of solar equipment decreasing more than 25 per cent, and perhaps not that much. So why is this development going to be so important? Because other energy costs are going to go up.

If you buy a piece of solar hardware today, you are guaranteed your energy price for the next 20 or 30 years. The cost of the sunshine isn't going to go up and you have already bought your conversion equipment. If somebody came to you and said, "For 70 cents a gallon, I'll sell you all the gasoline your cars are ever going to need for the rest of your life, and I'll store it for you without cost; all you have to do is come to me and get it", I think most of us would accept that offer immediately, because we know that before we go down the road much further, we're going to have to pay more than that for our gasoline, and we may not always be able to get it. So if we can buy our heat for our houses for the next thirty years at today's price, that's a good buy. That is what solar can do for you.

I think the future of solar heating is assured. Solar cooling is uncertain because additional complex and expensive equipment is required. It may not be something that a householder will want to be troubled with, and the costs may not be attractive. In commercial buildings where routine maintenance is usually carried out, and where cooling requirements are higher, solar cooling may become important. Much more technical development is needed in the solar cooling area.
Solar water heating is going to be common practice all over the country. Hot water is needed the whole year, so this solar system is used effectively 12 months of the year. An investment in a system that is working all the time provides greater economic return than one utilized in only one season. In the northern tier of states, where winters are long and residential cooling is not required, the combination of solar space heating and hot water supply should have spectacular growth.