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AN ANALYSIS OF SOLAR PANEL ASSEMBLY AS A PRISON INDUSTRY

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PREFACE

The Technology Applications Team at SRI International has been active in the NASA Technology Transfer Program since July 1, 1969. The Program's objectives are to transfer aerospace technology for the solution of important technological problems in public safety and transportation, to implement and refine appropriate methods for ensuring successful transfers, and to provide appropriate visibility for program activities. This study was prepared as part of the SRI Team's effort to develop a NASA Technology Transfer Program in the field of corrections.

I INTRODUCTION

The California State Department of Corrections (DOC) has established prison industries that benefit the inmates and the people of California. Primary among these industries is the fabrication of office furniture for all state agencies/departments and of vehicular license plates for the Department of Motor Vehicles. These industries assuage financial problems and boredom of the inmates and develop marketable skills useful in reestablishing them in society after their release from prison. The public benefits from the conservation of tax dollars, the rehabilitation of inmates, and the resulting reduction in second offenders.

In recent years, prison populations have been increasing at an accelerated rate. Consequently, existing prison industries are unable to provide employment for all job-seekers. This situation fosters antagonism among the inmates that often erupts into violence. To alleviate this hostile environment, consideration is being given to the establishment of a new prison industry.

The California State DOC is considering solar panel assembly as a prison industry provided that it meets the prerequisites for a prison industry. Among these requirements are: (1) product market with a state agency or department; (2) job skills development; (3) machine shop, small assembly plant, or other basic facility; (4) readily supervised production; and (5) no adverse effect on the private industry. Additionally, inmates could look forward to participation in an interesting new conservation industry--the solar energy industry. The concept for introducing solar assembly as a prison industry was originally developed as a result of the national needs assessment survey conducted by the SRI Technology Applications Team (TATeam) in August 1979.

The National Aeronautics and Space Administration (NASA) has been active for many years in the development and utilization of solar energy. In particular, NASA's Marshall Space Flight Center (MSFC) has tested new solar panel components and systems, as well as commercially available ones. The California State DOC believes that NASA's experience and technology would be beneficial in the establishment of a solar panel assembly industry in the prisons and has therefore requested the assistance of the NASA-sponsored TATeam at SRI.

SRI's TATeam assistance has begun with an analysis of the U.S. solar panel market and a separate analysis of the California market for solar panels. The analyses examine the current market for solar panels, the costs and features of existing products, the advantages and disadvantages of solar panel assembly as a prison industry, and particularly the effect of a solar panel prison industry on the private-sector solar energy industry as a whole.

II SUMMARY AND CONCLUSIONS

Study Findings

This section summarizes the findings of SRI's study on a solar panel industry for prisons. Details are provided in the rest of the report.

- The efficiency of currently available flat-plate solar collectors ranges from 35% to 95%, with the majority being 65% to 80% efficient. Developments are under way to improve efficiency, which, in turn, should improve the market.
- Prices for flat-plate solar collectors in California currently range from about \$10 to \$23/ft^2, depending on the materials and the manufacturers. In lot quantities, however, prices may be reduced by as much as 30% (i.e., \$7 to \$16/ft^2, which is still more than the projected \$6 to \$10/ft^2 price for prison-assembled panels.
- Californians consumed approximately 1.5 trillion ft^3 of gas and 113 billion kWh of electricity or 2.8 quads of energy in 1978. Solar energy accounted for about 0.001 quad, which was 200% of the 1977 solar consumption. In 1979, 0.002 quad of solar energy was consumed, representing 200% of 1978 solar consumption. If the rate of increase were to continue for 3 years and then stabilize at 125%, solar energy would account for 0.031 quad in 1985 (1.1% of total energy consumption) and 0.64 quad in 2000 (18% of total energy consumption).
- The 1.2 million ft^2 of solar collectors that were purchased in California in 1978 and about 2.1 million ft^2 in 1979 were almost entirely for water heating. Assuming 25% annual increases after 1981, the annual market for solar collectors could be about 10 million ft^2 in 1985, for an 8-year total of almost 40 million ft^2. Based on an average cost of \$18/ft^2, the monetary sales volume would be \$712.8 million. (The 1978 through 1985 sales volume for the United States would be 155 million ft^2 or \$2,793.6 million.)
- The 1978 through 1985 residential market in California, at 66.7% of the total market, would be \$475.4 million; the state and local government market, at 10%, would be \$71.3 million; the commercial/industrial market, at 20%, would be \$142.6 million; and the agricultural and other markets, at 3.3%, would be \$23.5 million--in 1980 dollars. These markets should be greatly increased after 1985, with annual sales exceeding 100 million ft^2 (\$1,800 million) by the year 2000 [a 67 million ft^2 (\$1,200 million) residential market, a 10 million ft^2 (\$180 million) government market, a 20 million ft^2 (\$360 million) commercial/industrial market, and a 3.3 million ft^2 (\$59 million) agricultural market].

- California consumed only 20% of U.S. solar energy in 1978, but it accounted for 26% of solar collector sales. This percentage difference is expected to continue.
- A survey of five state agencies revealed California state government markets of 3.46 million ft^2 for water heating:

	Million ft^2
Parks and recreational areas	0.20
Colleges and universities	2.26
Hospitals	0.40
Highway maintenance stations	0.01
Prisons	0.50

  Most of this market should be reached before 1990. A small additional market for headquarters and district office buildings and so forth is expected, primarily for new constructions. No survey was made of the local government agencies.
- A sample of 21 solar panel manufacturers, surveyed to determine their assessments of current and future markets, revealed small profits in today's marketplace and optimism for the 1980s. By 1989, sales volumes are expected to reach 151 million ft^2 (a 15-million ft^2 per year average).
- Solar water heating appears to be cost-effective when compared with electricity and in many cases is cost-effective when compared with natural gas. Electricity cost \$0.04/kWh in 1977, but is expected to cost from \$0.06 to \$0.07/kWh by 1985; the cost for solar energy (equipment plus installation) would be \$0.03 to displace 1 kWh. The price of gas in 1977 was \$0.30 to \$0.40 per therm in 1977 (compared with \$0.37 for solar energy) but is expected to reach \$0.60 or \$0.70 per therm by 1985. Solar energy is, of course, more cost-effective in Southern California.
- Annual fuel savings for a single household (family of four) at 80% efficiencies would range from \$300 to \$480 with a full solar system (water and space heating) or about \$109 (1980 dollars) for a water-heating system. In 6 years, the system would pay for itself (assuming a 55% tax credit).
- Fuel savings for the state of California could be \$6.2 million per year after 1992 with 3.4 million ft^2 of solar collectors operating at 80% efficiencies.
- Benefits to the DOC and the correctional industries include:
  - Job skills development for inmates in solar panel assembly and installation.
  - A ready market in state agencies of about 3.4 million ft^2 over the next 10 years: approximately \$1.4 million at \$6/ft^2, \$2.4 million at \$10/ft^2.
  - Employment for about 50 inmates half-time to produce 1333 to 2616 ft^2 per day for 6 to 10 years.

- Assistance from NASA's Marshall Space Flight Center, which has extensive experience in developing and testing solar systems.
- A low capital investment of about $100,000 for presses, dies, and a tank for pressure tests.

Conclusions

Based on the results of the market and cost/benefit analyses summarized above, the conclusion is that solar panel assembly is a viable industry for correctional institutions in California. It appears to meet all prerequisites for a prison industry: (1) a state-agency market for solar panels does exist; (2) job skills (solar panel assembly and installation) for about 50 inmates would be developed; (3) facilities are available for a small assembly plant at San Quentin Prison; (4) production can be supervised readily as indicated by the current cottage-shop operation in the minimal-security Growlersburg Conservation Camp where inmates assemble and install about 200 solar panels each year for the Department of Parks and Recreational Areas; and (5) the stage-agency market of less than 4 million ft^2 over the next 10 years represents about 6% of California sales (based on an estimated total market by 1990 of 60 million ft^2) and therefore should have only limited adverse effect on private solar industry. In consideration of the potential for negative effect on the private sector, the market area was limited to state agencies, rather than all tax-supported agencies within the state--i.e., county and local agencies.

During the period that this market analysis was under way, the California Correctional Industries Commission was studying the impact on the private sector of a solar-panel-assembly prison industry. Conclusive findings were not established to assure the Commission that such an industry would have no adverse effects, and industry plans were set aside.

The market analysis was completed to provide information at some later time when the solar collector industry is established. There is a further need, however, for a study to examine the effects of a prison solar industry on the use of solar panels in county and municipal applications.

III BACKGROUND OF SOLAR ENERGY

For hundreds of years, civilization has been dependent on solar energy in the form of fossil fuels. Not until this dependency was threatened was serious consideration given to the direct conversion of the sun's power as an energy source.

Solar technology is not new. As early as 1885, solar water-pumping systems had been developed. Worldwide attention was first focused on solar energy in 1955 at the World Symposium on Applied Solar Energy, held in Phoenix, Arizona. At that time, only sun-rich countries, or sections of countries, were using solar energy. In 1955, one property of the U.S. Forest Service located near Tucson, Arizona, was the only 100% solar-heated building in operation. The number of solar-heated homes 20 years later was only 300, and most were not 100% solar-heated. The slow progress of solar technology has been related primarily to the restriction of the use of solar energy to sun-rich areas--that is, to a limited market where it has been cost-effective when compared to the cost of other fuels.

Only where the net private benefits to be gained at least approach the cost of conversion will solar systems sell. According to solar energy equipment manufacturers, however, solar energy can be cost-effective in many locations with only moderate amounts of sunshine (not as a replacement for conventional heating, but as a 30% to 90% supplement). With any solar system, the initial cost may be high; however, once installed, fuel is free and maintenance is almost nonexistent. Most home systems pay for themselves in 2 to 8 years, according to a survey of solar home owners (New West in 1977). Thus, system acquisition can be viewed as a sound investment, particularly in California where up to 55% of the initial cost is allowed as a tax deduction for the property owner.

The limited use of solar energy has been attributed to two additional conceptions or misconceptions: the industry's technological infancy, and the abundance of undiscovered fossil fuel reserves. First, solar technological maturity has been reached as indicated by the more than 250 companies nationwide that were developing solar systems by the late 1970s. These include major corporations, such as PPG Industries, Reynolds Metals, Owens-Illinois, Revere Copper & Brass, and subsidiaries of Exxon and Mobil Oil. (The San Francisco yellow pages list 50 manufacturers/distributors of solar collectors.) Second, fossil fuels are not abundant. Even if actual oil reserves are five times the amount of current calculations, total consumption will be realized within 50 years with current rates of accelerated usage.* Furthermore, many large oil discoveries

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*Clark, Wilson, Energy for Survival: The Alternative to Extinction (Anchor Press, California, 1978).

of recent years have been in such locations as the North Sea, where staggering extraction and transportation costs have stalled production, or in the turbulent Middle East. Coal reserves also are limited; if the actual coal reserve is five times the known coal reserves, the supply would last only about 150 years.

Despite the immense amount of solar energy falling on the surface of the earth, direct use of this energy is not possible because of the low density of the radiation and the accompanying low temperatures. To be useful, the radiation energy must be concentrated. The collector performs this function by raising the temperature of the contained liquid or gas. The maximum temperature obtainable is determined by the physical principles of operation of the collector type or by cost considerations. A wide variety of solar collectors is available.

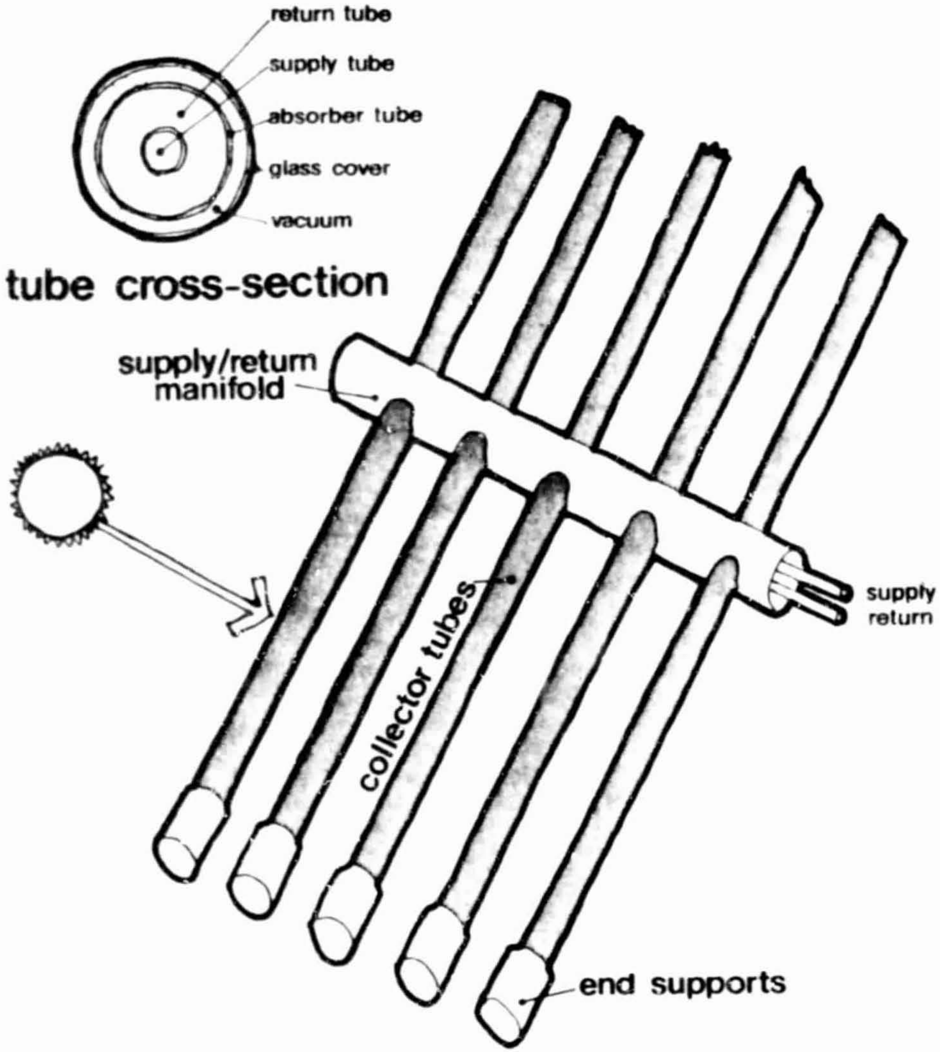
The evacuated tube solar collector is a series of cylindrical tubes (Figure 1). Each tube is actually three concentric tubes, with a vacuum between the outer and middle tubes (hence its name). The liquid or gas follows a path back and forth through the concentric tubes and picks up heat as it travels.

Parabolic collectors, as the name implies, are paraboloidal disks or troughs with reflective surfaces that concentrate large amounts of solar energy on a small area (Figure 2). Parabolic collectors are movable and can track the sun. The stationary reflector tracking absorber (SRTA) collector is similar to the parabolic collector except that the reflector is stable and only the absorber tracks the sun (Figure 3).

In a solar pond, the use of a plastic cover and a black liner enhances the ability of a shallow body of water to absorb energy. To prevent the water with the lowest density (highest temperature) from rising to the top and being lost to the outside air, salts that stabilize water density are added.

The flat-plate collector (solar panel) consists of a black metal plate covered with transparent glass or plastic that is backed with insulation (Figure 4). The black plate is the absorber and may contain tubes (Figure 5) through which the liquid circulates or may have an air space between it and the insulation. Solar radiation passes through the glass and is absorbed by the black surface, increasing the temperature of the metal. (The glass cover also prevents the loss of most of the heat to the atmosphere.) Heat from the metal is transferred to the gas or liquid. Collector temperature is regulated by the rate of the liquid flow. Heat loss is proportionately greater as the rate of flow is increased. Hence, a slower rate, with resulting lower temperature (about 104°F to 201°F), is most efficient. The flat-plate collector is the most commonly used type of collector, and it is the one the DOC is considering for state prison production.

Inexpensive, simple methods to store power during the absence of solar radiation are necessary for the exploitation of solar energy. The storage device may be an insulated tank or rock bed. In addition, a



SOURCE: Solar Business Office – Business and Transportation Agency

One type of evacuated tube collector is a recent development which utilizes a series of tubes with special absorptive coatings to collect solar energy. The tubes have the advantage that almost the same amount of surface area is exposed and perpendicular to the sun at any time during the day.

The evacuated tube collector is composed of a series of three concentric cylindrical tubes, with a vacuum (nearly zero air pressure) between the outer and middle tubes and a black selective coating on the outer surface of the middle tube. Water or air (usually water because of its higher specific heat capacity) is circulated from supply pipes through the inner tube. As it travels through this space it picks up heat. Upon reaching one end of a collector module, it enters the volume between the inner and middle tubes where it reverses flow direction and continues to build up heat content. It is then drawn off by the return tube and circulated into the heating system.

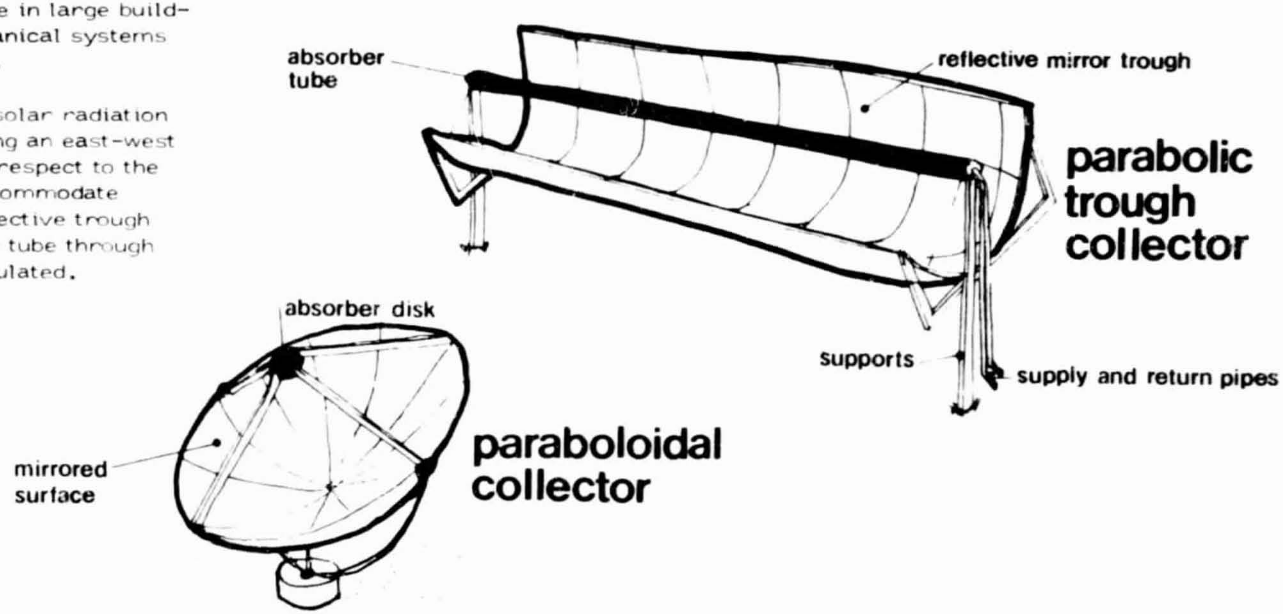
An evacuated tube system has the advantages of higher collection efficiency at standard operating temperature and the utilization of high temperatures in its collection process without excessive heat loss. The vacuum between the outer tubes of glass helps attenuate conductive and convective heat loss, but can do nothing for radiation heat loss. This latter loss can be decreased by applying a "selective surface" interior coating to the outer tube.

FIGURE 1 EVACUATED TUBE SOLAR COLLECTOR

The paraboloidal collector concentrates large amounts of solar energy on a small area. This concentration allows high temperatures to be attained. For effective collection, the parabolic concentrator must track the sun so the sun's rays are perpendicular to the frontal plane of the paraboloid. In the altazimuth system, the unit moves vertically to match the sun's altitude, and tracks horizontally to follow the solar azimuth during the day. Since the sun is in different positions every day, the tracking mechanism must be very sensitive and exact. This is likely to limit such devices to use in large buildings, where capital costs for mechanical systems may be offset by large fuel savings.

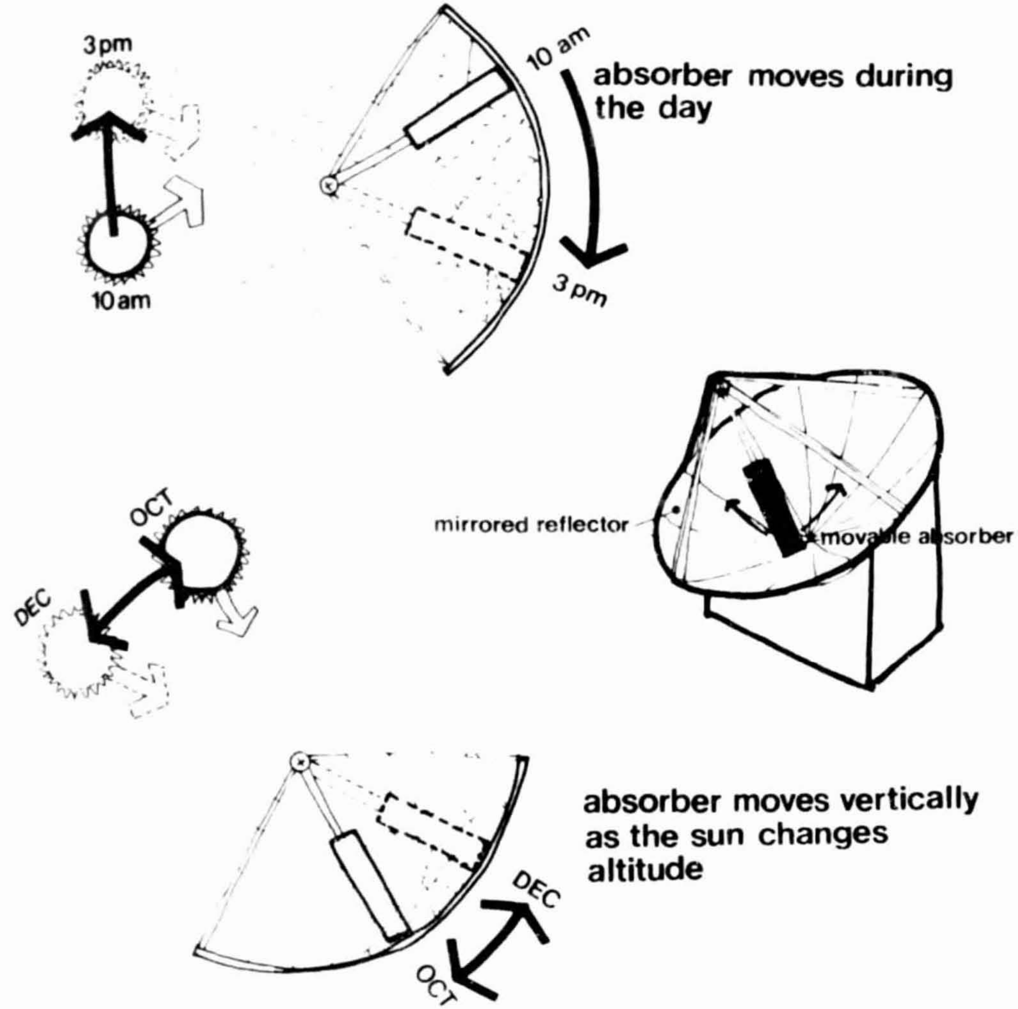
Another system to concentrate the solar radiation has a parabolic trough oriented along an east-west axis. The angle of the trough with respect to the horizontal is adjusted weekly to accommodate changes in solar altitude. The reflective trough concentrates energy on an absorber tube through which a heat absorbing fluid is circulated.

The paraboloidal surface of the collector is mirrored and reflective. Radiant energy is reflected onto an absorber area which is usually glass covered to minimize heat loss by convection and radiation. The absorber has a liquid circulating inside it to carry away the heat energy. It is essential to keep reflective surfaces very clean to avoid reflective loss.



SOURCE: Solar Business Office – Business and Transportation Agency

FIGURE 2 PARABOLIC SOLAR COLLECTORS

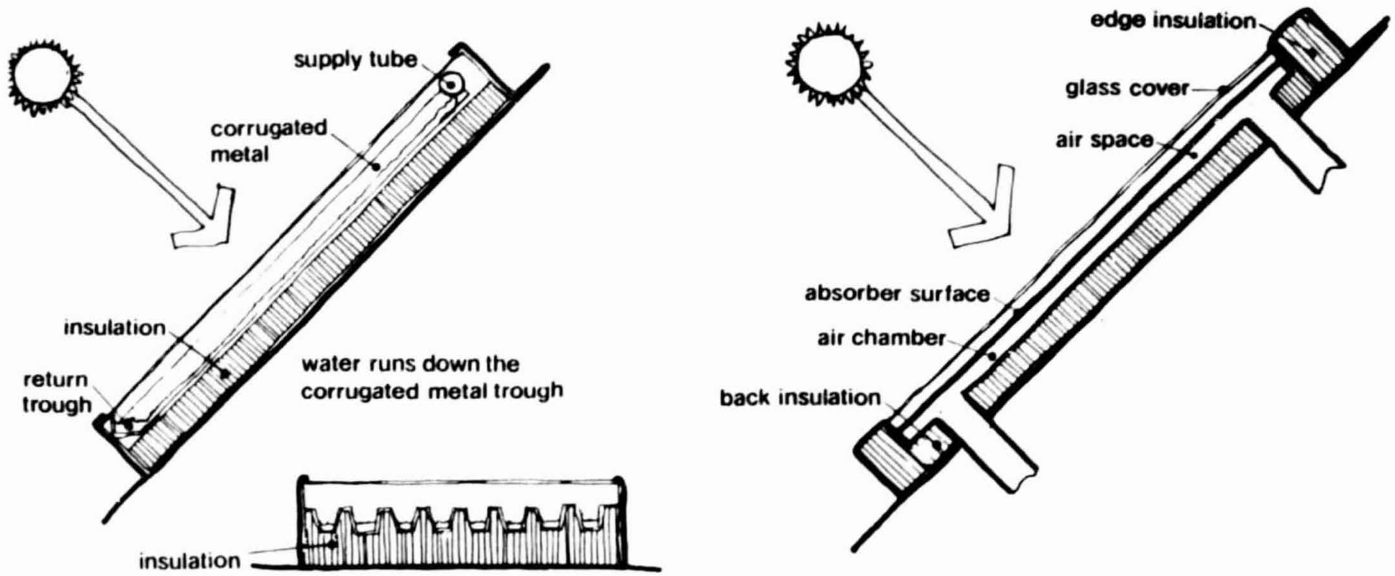


SOURCE: Solar Business Office — Business and Transportation Agency

FIGURE 3 SRTA SOLAR COLLECTOR

The major drawbacks to the parabolic collector are the high costs of optically precise surfaces, the need for expensive tracking mechanisms, and the difficulty in maintaining a clean optical surface. The SRTA (stationary reflector tracking absorber) collector is being developed to eliminate the need for tracking the sun with the mirror reflector. With this collector the hemispherical reflector is stationary and the absorber tracks the sun. The light energy is reflected off the mirror and onto the absorber.

The SRTA absorber is made up of tubing covered with glass. Fluid circulates in the tubing to transfer the heat. Since the temperatures in concentrating collectors far exceed those in flat plate collectors, the fluid used is usually not water. Whatever the fluid, it must nearly always be confined under high pressure to prevent boiling.

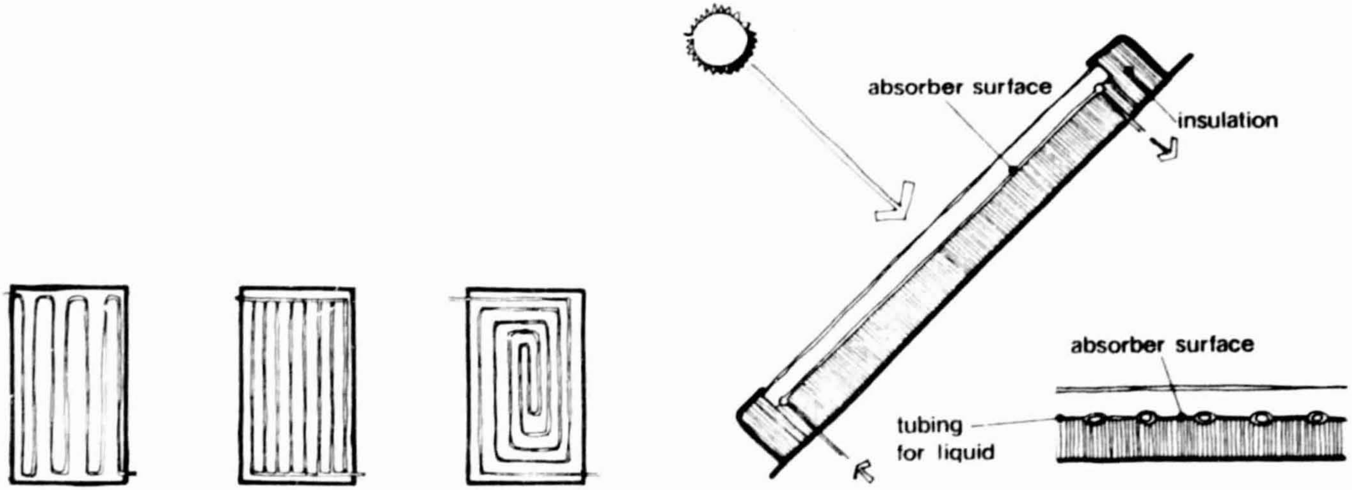


(a) THOMPSON "TRICKLE" TYPE OF COLLECTOR

(b) FLAT-PLATE AIR TYPE SOLAR COLLECTOR

SOURCE: Solar Business Office— Business and Transportation Agency

FIGURE 4 EXAMPLES OF FLAT-PLATE SOLAR COLLECTORS



SOURCE: Solar Business Office – Business and Transportation Agency

FIGURE 5 SCHEMATIC OF LIQUID FLAT-PLATE SOLAR COLLECTOR TUBES pump may be needed for circulating the heated liquid or gas within insulated pipes.

Today, solar energy conversion efficiencies of 60% to 70% for space heating and 80% to 90% for water heating are reported in sun-rich locations. Expansion of a hot-water system to include space heating for a family of four requires replacing an 82-gal tank with a central storage tank that holds at least 500 gal, replumbing to the new tank, and increasing the solar panel square footage by a factor of 4.

Additional information on solar heating may be obtained from the sources listed in Appendix A.

IV CURRENTLY AVAILABLE SOLAR PANELS

The California State DOC is considering the production of the flat-plate solar panel collector as a prison industry. Currently available solar panels come in three sizes, with prices ranging from about $10 to $23/ft²:

Panel Size	Specification (ft^2)
Small	<20.5
Medium	20.5 to 40
Large	>40

Price variations relate to differences in manufacturers and materials.

Data on solar panel efficiency, as reported by the various manufacturers, ranged from a high of 95% to a low of 35%. The majority of the panels have about 65% efficiency.

The SRI TATeam surveyed 21 solar panel manufacturers. Representative products are described below.

Solar Enterprises in Red Bluff, California, produces a liquid solar panel, the Hydro-Sol®, for $360. The small 3-$ft^2$ panel is surrounded by reflective shields that increase its area to 4 ft^2 and its depth to 15.5 in., giving a box-like appearance and enhancing its absorptive capability. Absorber plates as well as tubing are copper for excellent conduction and corrosion-resistance. The cover plate is glass; the insulation material is fiberglass. Adjustable supports enable positioning of the panel to take advantage of summer or winter latitudes. According to the manufacturer, two panels will provide energy for space and water heating for an average 3-bedroom home serving a family of four (up to 60 gal hot water per day). The panels are lightweight (17.4 lb) as well as small and are therefore ideal for installation on mobile homes. The efficiencies claimed range from 77% to 95%.

Advanced Energy Technology (AET), located in Los Gatos, California, specializes in liquid panels of minimal copper for lighter weight (53 lb dry) and lower cost. The AET SunLite® collector combines copper tubing with aluminum sheeting. That is, a 0.016-in. thick, highly conductive aluminum absorber plate is bonded (with electrically insulating material) to the flat sides of the copper tubes. The glazing, a one-way solar window, is a 0.02-in. thick polycarbonate material backed by Teflon®.

All components are encased in a unitized aluminum frame, giving an overall size of 4 × 8 ft. Efficiency claims are 80% for water heating and 70% for space heating. The price is $310 per panel. A 3-year warranty is provided.

Mor-Flo/American Corp. of Cleveland, Ohio, markets two different solar water-heating systems. The Solarstream® is designed for unlimited freeze protection; the Hotstream® is designed for limited freezing temperatures and for economy. The large (8 × 12 ft) but lightweight panels and standard hardware are purported to decrease installation costs. Single-glazed panels have a list price of $577 and double-glazed panels a list price of $672. All collectors carry a 5-year warranty.

Fafco Incorporated, located in Menlo Park, California, manufactures low-temperature liquid collectors, used primarily for swimming pool heating. At a 4- to 7-gal/min flow rate, the collector can maintain a pool-size volume of water at 8° to 15° above the ambient temperature. Material for the 4 × 8-ft collector is a specially formulated polyolefin. Collector efficiency estimates range from 65% to 85%. In October 1979, total installations by Fafco exceeded 20,000, all carrying 10-year warranties. The price per panel (32 ft^2) is listed at $505.

Specialty Manufacturing, Inc. in San Diego, California, produces Insolerator® panels. These panels combine copper tubing and plate with silver-brazed joints, tempered safety glass, and a copolymer frame to eliminate galvanic corrosion. The plates feature integrated manifolds for both plate and system flow. A 24-ft^2 panel costs $435. All panels are guaranteed for 5 years.

TechniTrek Corporation is an engineering and manufacturing firm in San Leandro, California, that specializes in cooling and water-separation systems. The TechniTrek solar collector contains an all-copper absorber system with silver-soldered joints, and a cast acrylic glaze that is curved to reduce wind resistance and increase solar penetration. The insulating material is a special fiberglass that will not out-gas and cloud the other surfaces. Panel size is 3 × 10 ft, with depth ranging from 3.5 to 6.5 in. due to curvature. The cost is $415 per panel. All collectors are covered by a 5-year warranty.

Solpower Industries, Inc. of Cupertino, California, produces a very basic solar collector for residential use. The 4 × 8-ft collector contains an all-copper absorber system and a glazing of ultraviolet (UV)-stabilized polycarbonate. Insulation is provided by high-temperature isocyanurate foam faced with 3-mil aluminum. Panels are priced at $400 and carry a 5-year warranty.

Energy Systems, Inc. (ESI) is a San Diego, California, manufacturer of solar systems with flat-plate solar collectors. The 3 × 6.3-ft collector frame is galvanized steel with baked enamel finish and glass fiber insulation. The absorber system contains copper manifolds and tubes and an aluminum absorber plate. The glazing assembly has two plates of tempered glass with aluminum desiccant spacer. Panels for water heating are priced at $366 each.

Revere Copper & Brass, Inc. of Los Angeles, California, makes its solar collectors available through regional distributors. The collectors contain an all-copper absorber system, with a unique design. Fluid channels are cast into the absorber plate, and then brazed to the top and bottom manifolds. The cover plate is glass; the frame is aluminum. The Revere collector measures 3 × 6.5 ft, an easily handled size. The price per panel is $230 wholesale, $365 retail.

Kaiser Energy Engineering of San Carlos, California, is a division of Dri-Honing Corp. Kaiser has developed the KEESON® hydronic solar panel (patent pending). The panel contains an all-copper absorbing system, a facing of tempered glass, a glass wool insulating blanket, and a bronze anodized aluminum frame. Company literature boasts of slow-flowing inlet and outlet ports (about 1 gal/min compared to >2 gal/min for most panels) to eliminate premature erosion. To provide a large heat exchange area, 19 closely spaced parallel tubes are fed by two sets of transverse flow-balancing connecting tubes. Overall size is 3 × 8 ft. The retail price of $460 per panel includes a 10-year warranty.

Heliodyne, Inc., located in Richmond, California, is a major manufacturer of solar products. The Heliodyne flat-plate collector has an all-copper absorber system, tempered glass glazing, glass fiber insulation, and a bronzed aluminum frame. The 33 integral channels of the absorber plates provide a large wetted surface and uniform flow for good efficiency. The self-supporting frame requires few mounting supports. Each panel measures approximately 3 × 8 ft and is priced at about $450.

Of major importance in the selection of a solar collector is the materials composition to ensure efficiency and durability. Table 1 lists the materials, overall size, and price (without installation) of the absorber system and the panel cover for each of the afore described collectors. The table reveals that collectors with all-copper absorber systems and tempered glass covers have a price range of $18 to $23/ft^2, the average price being $20/ft^2. Prices for collectors with absorber plates of aluminum (or a polymer) or polymer glazes, or both, range from $10 to $19/ft^2, with a $14.60/ft^2 average. The advantage of copper and glass is primarily their resistance to both galvanic corrosion (due to contact with the copper tubes) and degradation. This advantage is balanced against the generally lighter weights and lower prices of the aluminum and polymeric systems. Prices quoted are for one or two collector panels; the prices decrease markedly as the quantities increase; i.e., four small collectors should cost less than two large ones for the same water heating capacity. Representative panels are shown in Figure 6.

Omitted from the above is the integral solar water heater, which until recently was the domain of the owner-builder. This system, consisting of a black water tank(s) placed in a transparent insulated box, unites heating and storage functions. Currently, at least five commercially produced "breadbox" systems are being marketed nationwide.

Table 1

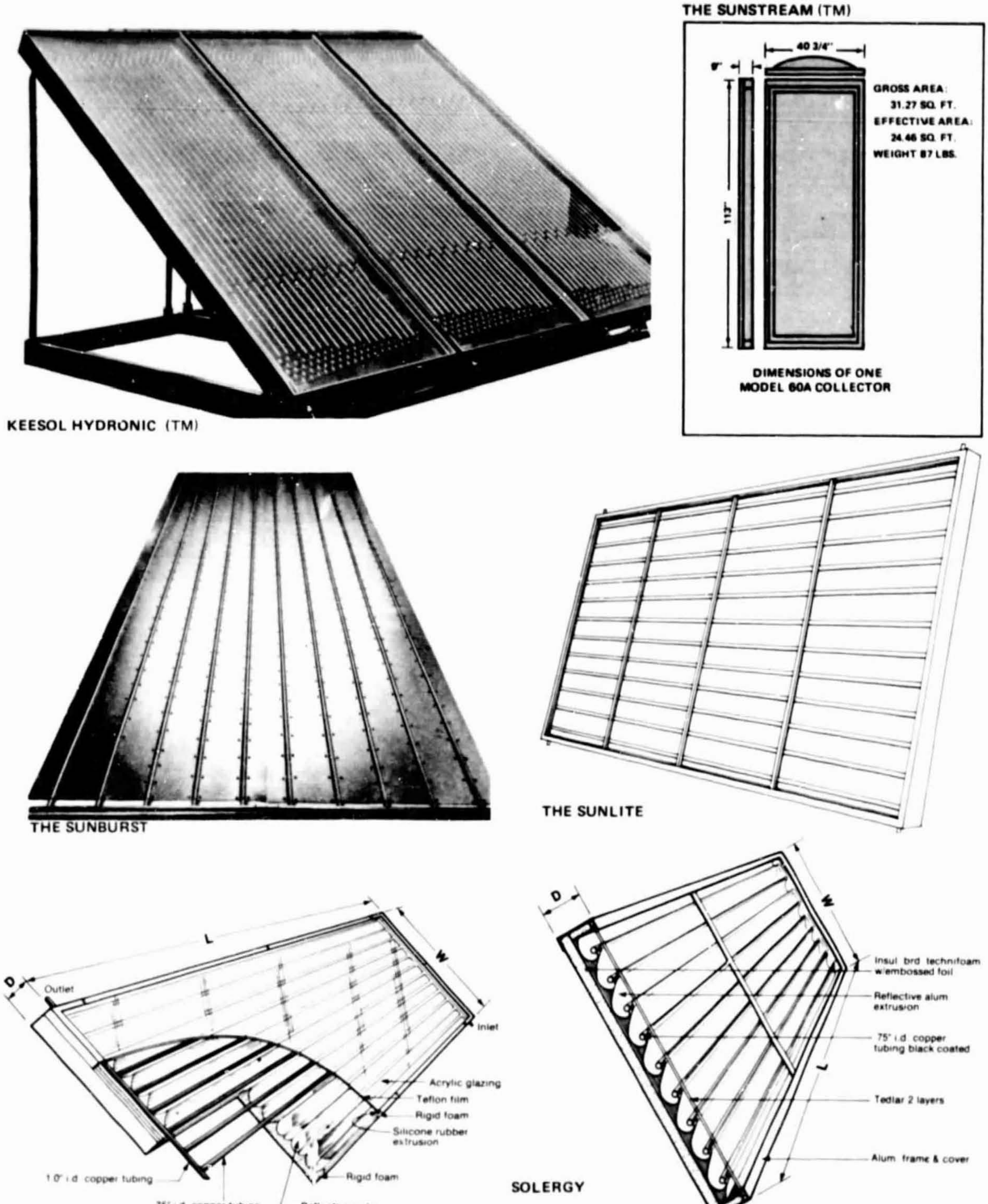
REPRESENTATIVE SOLAR COLLECTORS

Manufacturer	Size (ft^2)	Absorber System/Cover Materials	Special Features	Retail Prices (dollars) Per Panel*	Per ft^2
Advanced Energy Technology	30	Aluminum/polymer	Lightweight	310	10
Energy Systems	19	Copper/aluminum/glass	None	366	19
Fafco	32	Polyolefin	Glazed-plastic panel	505	16
Heliodyne	24	Copper/glass	Self-support frame	450†	19
Kaiser Energy	24	Copper/glass	Slow flow	460	19
Mor-Flo/American	48	Aluminum/polymer	None	577	12
Revere	19.5	Copper/glass	Cost fluid channels	365	19
Solar Enterprises	16	Copper/glass	Box-like frame	360	22.50
Solpower	32	Copper/polycarbonate	None	400	12
Specialty Manufacturing	24	Copper/glass	Lightweight copolymer frame	435	18
TechniTrek	30	Copper/acrylic	Curved acrylic glaze	415	14

*Effective December 1979.

†Approximate price range.

Source: SRI International



SOURCE: Heliodyne, Inc.

FIGURE 6 REPRESENTATIVE SOLAR PANELS CURRENTLY AVAILABLE

V NASA CONTRIBUTIONS TO SOLAR TECHNOLOGY

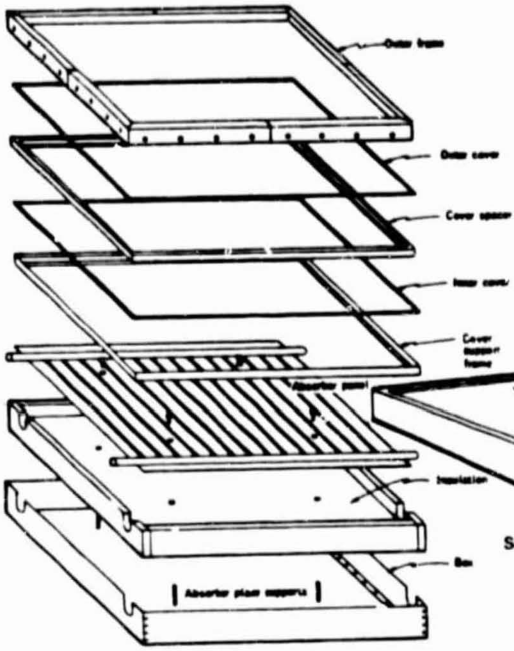
From its inception, NASA has included solar energy as a source of power in its spacecraft. Three of NASA's eight centers conduct solar energy research: Lewis Research Center (LeRC), the Jet Propulsion Laboratory (JPL), and Marshall Space Flight Center (MSFC).

NASA's LeRC, located in Cleveland, Ohio, is researching solar energy-conversion processes and systems for propulsion in the air, in space, and on the ground; the generation and storage of electrical energy in both terrestrial and space applications; and materials and structures for such systems. Much work is in progress to improve the efficiency of present-day energy-conversion processes and to develop hardware and systems for the application of alternative energy sources. Activities related to the use of alternative energy sources include solar energy conversion by means of solar cell arrays and solar photovoltaic power systems.

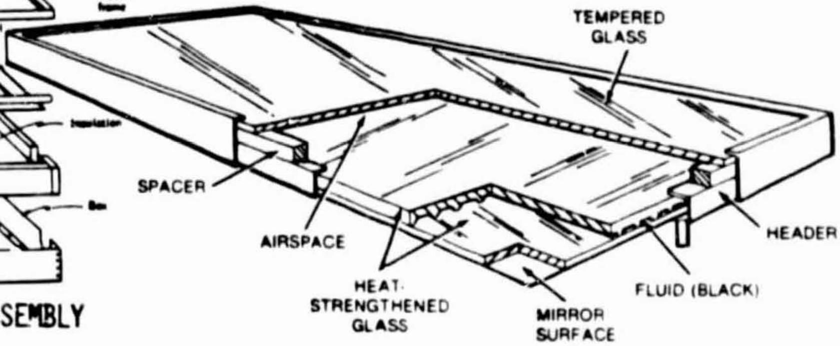
NASA's JPL is located in Pasadena, California. This center is best known for its mission control of unmanned space exploration vehicles and satellites. Areas of expertise include telecommunications, deep space network operations, advanced electronics, and solar energy conversion for exploration vehicles and satellites. Solar energy activities are directed primarily toward solar cell improvements, solar power conditioning, and solar concentrators.

NASA's MSFC in Huntsville, Alabama, has been given primary responsibility for the design, fabrication, assembly, and testing of large spacecraft structures and propulsion systems for the Saturn, Skylab, and Shuttle programs. Other responsibilities include the space sciences and solar energy conversion. At MSFC solar energy R&D efforts are concentrated on the flat-plate solar collector--the solar panel. A large facility is available for accelerated testing of solar panels. MSFC experience in the development and testing of solar systems has benefited more than 25 manufacturers.

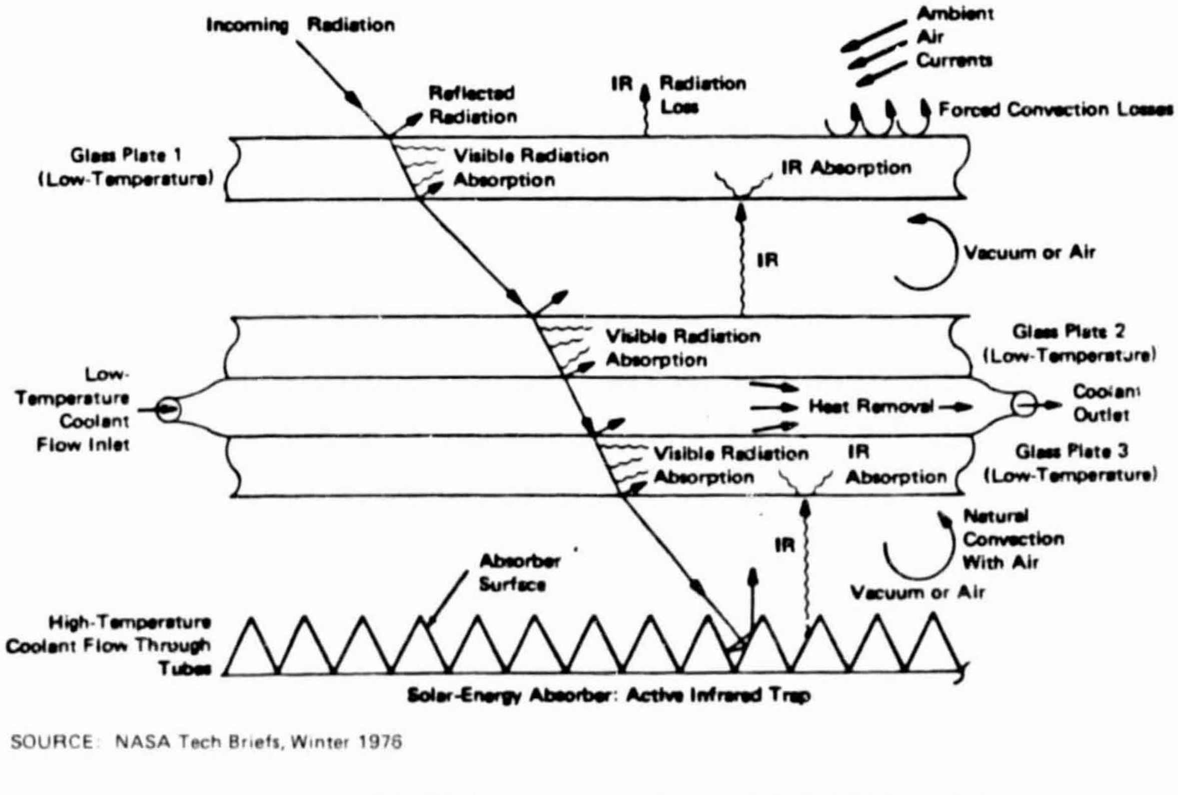
Examples of recent NASA contributions to solar panel technology include a corrosion-resistant, all-glass collector; a tubeless flat-plate collector (a single sprayhead replaces many tubes); performance testing of numerous solar collector materials and systems; installation, operation, maintenance, and repair manuals; a more efficient solar energy absorber that traps infrared heat; a black nickel plating for aluminum that increases solar absorption to 93%; an evacuated concentric glass-tube-envelope collector that surrounds a flat-plate absorber to improve efficiency; and other coating, film, and glazing improvements. Representative solar panel technologies developed by NASA are provided in Figure 7 and in Appendix B.



SOLAR ENERGY COLLECTOR ASSEMBLY

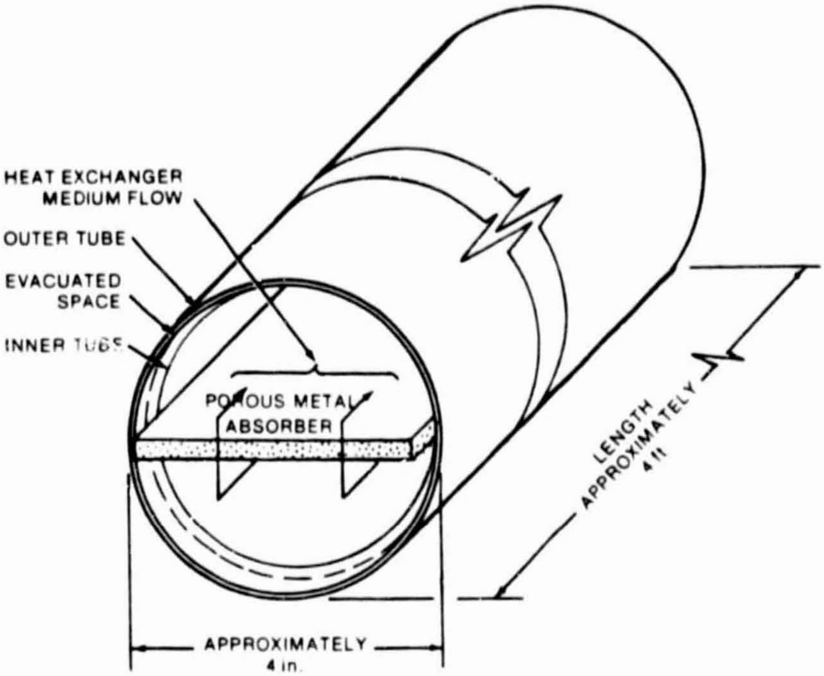


An **All-Glass Solar Collector** is corrosion-free and more economical without conventional fluid-carrying metal tubes. It utilizes black fluid to absorb solar heat. A mirrored surface on the bottom reflects any heat lost back to the fluid.

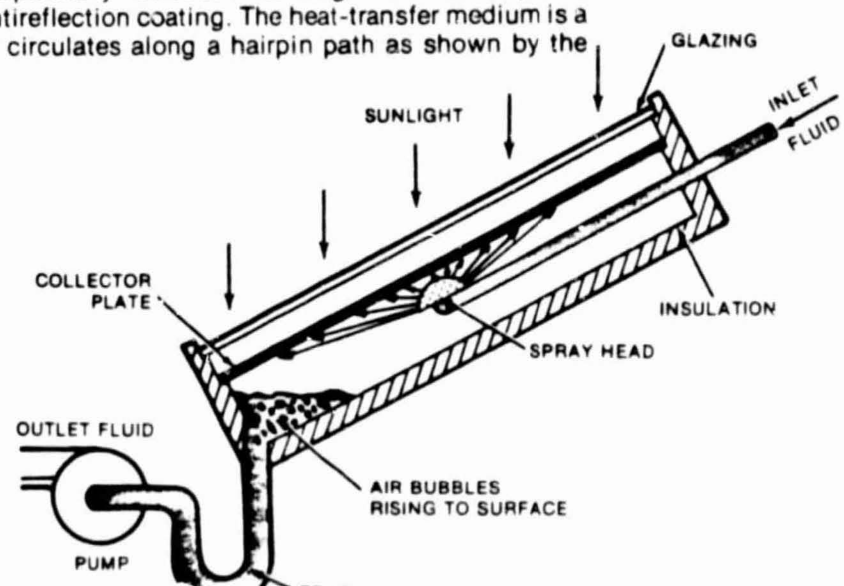


SOURCE: NASA Tech Briefs, Winter 1976

FIGURE 7 REPRESENTATIVE NASA SOLAR PANEL TECHNOLOGY



The **Concentric Glass-Tube-Envelope Collector** surrounds a flat-plate absorber having a spectrally selective coating. The envelope is transparent with an antireflection coating. The heat-transfer medium is a gas, such as air, that circulates along a hairpin path as shown by the arrows.



Efficient Heat Transfer Without Pipes in a solar-energy collector might be possible by spraying the heat-transfer fluid against the underside of the collector plate. A single spray head or an array of spray heads might be used. The chief advantage of this approach would be the relaxation of materials requirements, as high thermal conductivity of the absorber plate material is no longer a critical selection parameter.

FIGURE 7 - REPRESENTATIVE NASA SOLAR PANEL TECHNOLOGY (Concluded)

An additional NASA project that included solar technology was the construction of the Technology Utilization House (Tech House) at NASA's Langley Research Center (LAC) in Hampton, Virginia. The project purpose was to demonstrate to the building industry and the public the benefits of solar energy and other energy and resource conservation technologies. Tech House was opened to the public in 1976. A brief description of the house is provided in Figure 8.

The NASA Technology Utilization House (Tech House), constructed at Langley Research Center, was designed and built to demonstrate how the application of aerospace technology could advance the building industry in residential construction. Tech House is a single level structure of contemporary design which is comprised of two square modules connected by a hallway and contains approximately 140 m^2 (1,500 ft^2) of living space. One module consists of a living room, dining area, and kitchen; the other, three bedrooms and two baths. The connecting hallway has an entry vestibule and a laundry room. In developing Tech House, NASA incorporated the latest technology and used special features when either the initial cost could be recovered in energy savings over the useful life of the feature or if it provided a specific benefit such as personal or structural safety. The one other criterion for application of advanced technology was that the feature was projected to be commercially available within five years.

It is forecast that within five years the house with all its special features can be built commercially for approximately $45,000 (based on 1976 costs). With the incorporation of solar energy, energy efficient appliances, and the water reuse system, it is predicted the homeowner would save approximately $20,000 in utility costs over a period of twenty years, after recovering the additional cost of these special features. (This forecast is based on a ten-percent annual increase in utility costs.)

The following special systems and features, most of which are an outgrowth of NASA's aerospace technology, have been incorporated into Tech House:

Heating and Cooling System

- Solar collectors on the roof are used, together with nighttime radiators, two wells, and a heat pump, to supply major heating and cooling requirements.
- Additionally, the fireplace is outfitted with a duct system to bring in combustion air from the outside, and fire grate water coil, enabling the accumulation and storage of heat for later distribution.
- Exterior retractable shutters provide energy savings when closed by preventing heat loss during the winter and heat gain during the summer and, at the same time, function as a security measure.
- A nonflammable, nonpetroleum based foam provides highly efficient insulation, supplemented by metal exterior doors which have a thermal break, polystyrene core and magnetic weather stripping.

Water Recycling System

- A 50-percent reduction in water consumption is attained through use of low-profile water fixtures and a water reuse system which collects waste water from the shower, bathtub, bathroom sinks, and laundry in a holding tank where it is chlorinated, filtered, and recycled for toilet flushing.

Hot Water System

- Solar energy heats the water used in the domestic hot water system.

Security System

- Interior security is provided by detectors at doors, windows, and under carpets which set off an alarm when an intrusion occurs.
- An exterior security system uses a seismic device to sound an alarm when an intruder approaches within 80 m of the house.
- A smoke detector is used to sense the presence of combustion products and sound an alarm.
- A battery charged by a solar cell provides power for a driveway spotlight and emergency lighting. The smoke detector and security system may also be powered by the solar-charged battery.
- A tornado detector is attached to the television screen and sounds an alarm upon the appearance of a

NASA's **Tech House** at Langley Research Center incorporates solar heating, cooling, and hot water. A security system includes intruder and fire alarms, a tornado detector, and emergency lighting. A water recycling system and energy-saving lighting fixtures help reduce the homeowner's costs.

SOURCE: NASA Tech Briefs, Winter 1976

FIGURE 8 NASA TECHNOLOGY HOUSE

tornado within a radius of 18 mi.

Additional

- Thermistors installed in lamp sockets significantly increase the life of the light bulbs by a minimum of 300 percent.
- Seat custions are made of an advanced foam rubber that contours to a body shape, thereby distributing weight evenly over the contact surface.
- Flat conductor electrical wiring, covered with plastic baseboard, which has greater current capacity was installed after the building was completed and the carpet installed.

These features are all examples of the innovations utilized in the construction of the Tech House to demonstrate the application of advanced technology to minimize energy and water consumption and provide for the comfort and safety of the homeowner and his family.

This work was done by the Technology Utilization Office of **Langley Research Center.**

While no patent action is contemplated by NASA on the Technology Utilization Home as such, many of the components and systems included in the house are covered by patents. Some components were developed by private industry and industry owns those patents. Inquiries regarding which items are patented and concerning rights for the commercial use of these inventions may be directed to the Patent Counsel, Langley Research Center, Mail Stop 279, Hampton, VA 23665. Refer to LAR-12134.

SOURCE: NASA Tech Briefs, Winter 1976

FIGURE 8 NASA TECHNOLOGY HOUSE (Concluded)

VI MARKET FORECAST FOR SOLAR PANELS

Any estimate of the solar panel market must be based on statistics for solar energy consumption displacement of conventional energy consumption. According to the U.S. Department of Energy (DOE), 75 quads of conventional energy were consumed in the United States in 1976. A quad equals ~1 trillion ft^3 of natural gas or 85 billion kWh of electricity and is used here for convenience in relating solar power to the various conventional power sources. Because the quantities of gas and electricity consumed in the United States are approximately equal, the 75 quads might translate into 36 trillion ft^3 of gas and 2.9 trillion kWh of electricity combined, plus an allowance for coal and oil. (Gas and electricity currently account for 93% of U.S. heating sources.)

Energy Consumption in California

California's three major utility companies sold 112 billion kWh of electric power in 1977 and 113 billion in 1978, an increase of ~1%. The same three companies show no increase in gas consumption. The trend toward energy conservation is evident in these figures.

If the trend continues--that is, if energy consumption in California increased at no more than 1% per year--then in 1985 the electric power consumption would be 121 billion kWh and the gas consumption would be 1.5 trillion ft^3. This represents a 7% maximum increase over 1978 consumption. Interestingly, the U.S. DOE predicts a minimum increase in national energy consumption of about 6% for 1978 through 1985--that is, 3.1 trillion kWh of electricity and 38 trillion ft^3 of gas. The DOE also estimates that solar energy will displace 8.5 billion kWh of electricity and 0.1 trillion ft^3 of gas in 1985.*

California's consumption of electricity and natural gas accounted for ~4% of the total U.S. consumption in 1976. Projecting this percentage into 1985, along with an assumed increase of 1% per year, gives an estimated electricity consumption for California of 119.4 billion kWh and a gas consumption of 1.48 trillion ft^3, and 1.1% solar energy displacement (1.3 billion kWh and 0.016 trillion ft^3). In Table 2, these energy figures are converted into quads for convenience.

In the year 2000, California's total energy consumption would be 138 billion kWh of electricity and 1.6 trillion ft^3 of gas, without solar

*U.S. Department of Energy, "Solar Energy, A Status Report," DOE/ET-0062, June 1978.

Table 2

ESTIMATED CALIFORNIA ENERGY CONSUMPTION, 1985 AND 2000

	Number of Quads*	
	1985	2000
Electricity	1.40	1.30
Gas	1.48	1.28
Solar	0.03	0.64
Total	2.91	3.22

*One quad approximately equals 1 trillion standard ft^3 of natural gas or 85 billion kWh of electricity.

Source: SRI International (Based on an estimate of 25% annual increases in solar energy consumption beginning in 1982).

energy. If a 25% per year increase in solar energy is assumed beginning in 1982, solar energy would represent 20% of total gas and electric consumption in the year 2000; that is, solar energy would displace 27.6 billion kWh of electricity and 0.32 trillion ft^3 of gas. Electricity consumption would be reduced to 110.5 billion kWh and gas to 1.28 trillion ft^3.

This information is provided as a basis for the solar panel market analysis. At this writing, most solar energy consumption deals with solar panels.

Current and Projected Solar Panel Sales Volume

In 1978, more than two-thirds of the solar collectors sold were used for residential applications. Most of these collectors were purchased by individual homeowners or by small construction firms (see Table 3). The number of solar homes constructed by major home builders is expected to increase dramatically, however, when the housing industry recovers from its slump.

It should be noted that nearly twice as many collectors were sold in 1978 as in 1977, and the growth rate continued in 1979. According to the U.S. DOE, 4.8 million ft^2 of solar collectors were sold in 1978.

Table 3

SOLAR COLLECTOR BUYERS
IN THE UNITED STATES IN 1978

Category of Buyer	Percentage of Total Sales	Number of Square Feet
Major homebuilders*	5	240,000
Individual homeowners and small construction firms	65	3,120,000
Government agencies	20	960,000
Other	10	480,000
Total	100	4,800,000†

*More than 75 units per year.

†Gerlach, K. A., "Solar Heating Market Survey of Major Home Builders," SRI International, Menlo Park, California (1979).

Californians purchased 26% of these collectors (1.2 million ft^2) and New York and Florida 10% each (0.48 million ft^2 each). No other state exceeded 4% of the total sales volume. (See Table 4.)

Table 4

STATE PERCENTAGES OF SOLAR COLLECTOR SALES IN 1978

State	Percentage of Sales
California	26
Florida	10
New York	10
Connecticut	4
Ohio	4
Virginia	4
Minnesota	3
Arizona	2
All others	37
Total	100

Source: SRI International

For the years 1978 through 1985, solar panel total U.S. sales are expected to reach 119.6 million ft^2 ($2.2 billion at an average of $18 per ft^2). At regularly increasing increments, based on 25% per year increases after 1980, sales in California would be $57.6 million for 1980, $90.0 million for 1982, and $142.2 million for 1984. (See Table 5.)

Table 5

FORECAST OF TOTAL U.S. SOLAR COLLECTOR SALES

	Sales Volume (million ft^2)			Dollar Sales Volume* (millions)	
Year	United States	California	U.S./CA Percentage of Previous Year	United States	California
1978	4.8	1.2	175	86.4	21.6
1979	8.4	2.1	150	151.2	37.8
1980	12.6	3.2	125	226.8	57.6
1981	15.8	4.0	125	284.4	72.0
1982	19.7	5.0	125	354.6	90.0
1983	24.6	6.3	125	442.8	113.4
1984	30.8	7.9	125	554.4	142.2
1985	38.5	9.9	125	693.0	178.2
Total	155.2	39.6		2,793.6	712.8

*Based on 1980 history, 25% increases after 1980, and 1980 dollars at $18/ft^2.

Source: SRI International

If California's solar energy consumption were to grow from 0.001 quad in 1978 to 0.031 quad in 1985 as indicated in Table 2, solar collector sales for that 8-year period would be 39.6 million ft^2. At an average cost of $18 per ft^2, the dollar value would be $712.8 million, with $71.3 million for state and local government facilities (Table 6) or about $35 million for state agencies alone.

In California, the solar panel sales volume appears to be larger than the amount of solar energy consumed would indicate. California's 0.002 quad of solar energy consumption in 1978 represented 20% of total consumption and 26% of sales. In Table 7, the ratios and projected ratios of U.S.-to-California solar energy consumption are provided for the years 1978, 1985, and 2000. As indicated, Californians are expected to consume approximately 18% of total solar energy consumption in 1985 and

Table 6

BREAKDOWN OF SOLAR PANEL MARKETS
IN CALIFORNIA THROUGH 1985

Market Area	Percentage of Total	Estimated Dollar Sales Volume (millions)
Residential	66.7	475.4
State and local government	10.0	71.3
Commercial/industrial	20.0	142.6
Other	3.3	23.5
Total	100.0	712.8

Source: SRI International (extrapolated from Department of Energy data for the first half of 1978)

Table 7

COMPARISON OF U.S. AND CALIFORNIA SOLAR ENERGY CONSUMPTION
(In Quads)

	1978 (actual)	Projected	
		1985	2000
United States	0.01	2.0	8.0
California	0.002	0.03	0.64
U.S./California ratio	5:1	6:1	13:1

*One quad equals ~1 trillion standard ft^3 of natural gas or 85 billion kWh of electricity.

Source: Based on information provided in U.S. Department of Energy Report, DOE/ET-0062.

8% in 2000. By projecting the relationship between the 1978 U.S.-to-California solar energy consumption ratio and the 1978 U.S.-to-California solar panel sales ratio, the California percentages for total sales can be estimated at 25% in 1985 and 10% in 2000 as compared with 18% consumption in 1985 and 8% in 2000 (see Table 8). Because California's percentage of solar panel sales volume is greater than its solar energy consumption percentage, it appears that Californians are purchasing larger solar systems than they need to for handling current energy consumption.

Table 8

CALIFORNIA PERCENTAGE OF SOLAR ENERGY CONSUMPTION
VERSUS SOLAR PANEL SALES

	1978	1985	2000
Ratio of U.S. to California solar consumption	5:1	6:1	13:1
California percentage of solar consumption	20	18	8
Ratio of U.S. to California solar panel sales	3.9:1	4:1	10:1
California percentage of solar panel sales	26	25	10

Source: SRI International

California State Agency Market

As stated earlier, the 1978 to 1985 forecast for solar panel sales volume in California is set conservatively at about 39.6 million ft^2. In 1978, residential applications represented ~67% of total sales, government 10%, commercial applications 20%, and other the remaining 3.3%. If this sales distribution continues, the state and local agency market could reach about 3.96 million ft^2 for the 8 years. This square footage represents approximately 0.17 million panels selling for $71.3 million (in 1980 dollars). To reinforce, or rectify, this estimate, the SRI TATeam surveyed six state agencies to solicit their viewpoints on agency use of solar panels. The agencies were chosen for the applicability of their buildings to solar heating.

California State Department of Parks and Recreational Areas

A survey of state parks and recreational areas revealed a total of 11,236 campsites in 102 camps. If all camps with 25 or more campsites (11,104) installed solar systems, 5,236 solar panels (48 ft^2/panel) would be required. This figure assumes an average need for 24 ft^2 per campsite (to accommodate an average campsite occupancy of three persons using hot water for showers only). Statistics on all 102 camps are provided in Table 9.

Discussions with appropriate parks and recreation personnel revealed a similar market estimate. The Parks Department currently has 1920 ft^2 of solar panels installed at two parks: 480 ft^2 at Brannon Island and 1440 ft^2 at Anza-Borrego Desert. Funds are available to continue solar systems installation, with project completion tentatively set for about 1985.

The panels currently installed were fabricated at Growlersberg Conservation Camp, which has about 80 prison inmates. The rate of system installation in the parks has been governed by the availability of panels from Growlersberg. According to park personnel, panel performance is excellent. Panel components include a fiberglass frame, a copper plate, and copper tubing. Each of the 4 × 8-ft panels cost the Parks Department \$170, or \$5.31/ft^2, in 1979. If Growlersburg is unable to satisfy the Parks Department's time schedule, other sources will be sought. (Growlersburg currently is producing 6,400 ft^2/year). The Parks' demand is expected to be about 44,000 ft^2 per year for 6 years.

California Department of Education

Educational facilities operated by the State of California are primarily concerned with higher education and fall within one of three educational systems: the University of California, the California State University, and the Community Colleges. Solar pool-heating systems are being considered for all campuses and solar hot-water systems for all resident-student campuses. The University of California maintains 8 campuses, the California State University comprises 19 campuses, and the Community Colleges include 98 campuses. Based on an assumption that all University of California campuses and all California State University campuses with full-time enrollments exceeding 1,000 have two swimming pools and that all others have one pool, the solar panel market for pool heating of more than 1 million ft^2 can be forecast as shown in Table 10.

Student housing is provided at all eight University of California campuses and at 15 campuses of the California State University. Currently, only housing on the San Jose State University campus is equipped with solar collectors for hot-water heating; however, installations for the housing at the San Francisco and Humboldt campuses are planned for the near future. If solar systems are provided for all student housing during the next 10 years, ~0.9 million ft^2 of solar collectors would be needed (see Table 11) to accommodate as many as 36,228 resident students.

Table 9

POTENTIAL SOLAR COLLECTOR MARKET
FOR CALIFORNIA STATE PARKS AND RECREATIONAL AREAS

State Park	Number of Campsites	Estimated Solar Collector Requirement (ft^2)
Andrew Molera	50	1,200
Anza-Borrego Desert	395	9,500
Atascadero	104	2,500
Austin Creek	24	600
Benbow Lake	76	1,800
Big Basin	196	4,700
Bodie	10	200
Bothe-Napa Valley	35	800
Brannan Island	102	2,500
Butano	40	1,000
Calaveras Big Trees	129	3,100
Carpinteria	261	6,300
Castle Crags	64	1,500
Castle Rock	24	600
Caswell Memorial	65	1,600
Clear Lake	82	2,000
Colusa-Sacramento	12	300
Cuyamaca	182	4,400
D. L. Bliss	168	4,000
Del Norte Coast Redwoods	145	3,500
Doheney	119	2,800
Donner Memorial	154	3,700
Dry Lagoon	30	700
El Capitan	85	2,000
Emerald Bay	120	2,900
Emma Wood	150	3,600
Folsom Lake	150	3,600
Fremont Peak	12	300
Gaviota	59	1,400
George J. Hatfield	7	200
Grizzly Creek Redwoods	30	700
Grover Hot Springs	76	1,800
Hendy Woods	92	2,200
Henry Cowell Redwoods	51	1,200
Henry W. Coe	41	1,000
Hollister Hills	235	5,600
Humboldt Redwoods	257	6,200
Indian Grinding Rock	21	500
Jedediah Smith Redwoods	108	2,600
Lake Elsinore	301	7,200
Lake Oroville	328	7,900

Table 9 (Continued)

State Park	Number of Campsites	Estimated Solar Collector Requirement (ft^2)
Lake Perris	250	6,000
Leo Carrillo	190	4,600
MacKerricher	143	3,400
Malakoff Diggins	30	700
Manchester	47	1,100
McArthur-Burney Falls	118	2,800
McConnell	17	400
McGrath	174	4,200
Millerton Lake	133	3,200
Montana de Oro	46	1,100
Morro Bay	135	3,200
Mount Diablo	60	1,400
Mount San Jacinto	83	2,000
Mount Tamalpais	16	400
New Brighton	115	2,800
Palomar Mountain	21	500
Patrick's Point	123	3,000
Paul M. Dimmick	28	700
Pfeiffer Big Sur	218	5,200
Picacho	80	1,900
Pismo	505	12,100
Plumas-Eureka	67	1,600
Point Mugu	150	3,600
Portola	52	1,200
Prairie Creek Redwoods	100	2,400
Red Rock Canyon	50	1,200
Refugio	85	2,000
Richardson Grove	169	4,100
Russian Gulch	30	700
Saddleback Butte	50	1,200
Salton Sea	1,190	28,600
Salt Point	31	700
Samuel P. Taylor	68	1,600
San Clemente	157	3,800
San Elijo	171	4,100
San Luis Reservoir	119	2,900
San Mateo Coast	50	1,200
San Onofre	313	7,500
San Simeon	134	3,200
Seacliff	26	600
Silverwood Lake	95	2,300
Sonoma Coast	130	3,100
South Carlsbad	226	5,400
Standish-Hickey	162	3,900

Table 9 (Concluded)

State Park	Number of Campsites	Estimated Solar Collector Requirement (ft^2)
Sugarloaf Ridge	50	1,200
Sugar Pine Point	125	3,000
Sunset	90	2,200
Tahoe	39	900
Turlock Lake	65	1,600
Van Damme	74	1,800
Woodson Bridge	46	1,100
Total	11,236	269,700

Note: At an average of $18/$ft^2$ in 1980 dollars, the estimated sales volume is $4.85 million. Assuming 24 ft^2 solar collector per campsite, the total requirement is 0.27 million ft^2.

Source: SRI International

Table 10

POTENTIAL SOLAR PANEL MARKET
FOR STATE UNIVERSITY/COLLEGE POOL HEATING

University/College System	Number of Campuses	Number of Pools	Potential Market (millions ft^2)*
University of California	8	16	0.16
California State University	19	25	0.25
Community College	98	98	0.97
Total	125	139	1.38

*Based on an assumed 9,890 ft^2/pool to provide 80° temperatures (with an average depth of 5 ft).

Source: SRI International

Table 11

SOLAR ENERGY FOR STUDENT HOUSING
AT THE UNIVERSITY OF CALIFORNIA
AND THE CALIFORNIA STATE UNIVERSITY

Location	Number of Resident Students*	Estimated Solar Requirements (ft^2)†
California State University		
Bakersfield	250	6,000
Chico	917	22,000
Dominguez Hills	0	0
Fresno	1,264	30,000
Fullerton	0	0
Hayward	0	0
Humboldt	1,034	30,000
Long Beach	868	20,000
Los Angeles	0	0
Northridge	536	13,000
Pomona	1,182	30,000
Sacramento	970	24,000
San Bernardino	308	8,000
San Diego	1,674	40,000
San Francisco	1,441	35,000
San Jose	1,765	43,000
San Luis Obispo	2,774	67,000
Sonoma	399	10,000
Stanislaus	161	4,000
University of California		
Berkeley	3,000	72,000
Davis	3,064	73,000
Irvine	1,550	38,000
Los Angeles	3,600	87,000
Riverside	1,200	30,000
San Diego	2,900	68,000
Santa Barbara	2,600	63,000
Santa Cruz	2,771	67,000
Total	36,228	880,000

*Based on 1979-1980 statistics supplied by the Auxiliary and Business Services Office, the State University and Colleges.

†Based on 24 ft^2 per student.

Source: SRI International

The solar hot-water system at the San Jose State University at San Jose was installed in two dormitories in 1976. These installations represented the nation's second largest functioning solar systems at that time. Each dormitory supported 4,500 ft^2 of solar collectors. Each flat-plated collector measured 34-1/4 × 82-1/2 in (see Figure 9).

The average hot-water consumption at the university in San Jose is 5,400 gal per day, or 27 gal per day per dormitory student. The solar system was designed to provide about 3 million Btus of heat per day. The amount of gas to heat this water before the solar installations was 1,200 therms per month (40 therms per day) for each dormitory. At $0.19 to $0.24 per therm (the 1979 cost range for natural gas in California), the annual fuel cost for each dormitory would range from $2,736 to $3,456. The cost for each San Jose solar panel array was $62,500 ($14 per ft^2). On the basis of assumed 10% to 16% biannual rate increases for gas, at least 12 years will be required for the system to pay for itself.

The 870,000 ft^2 of solar panels required for the remaining student housings would cost $12.2 million at $14 per ft^2 or $15.7 million at $18 ft^2.

Departments of Mental Health and Developmental Services

Unlike the Department of Parks and Recreational Areas and the Department of Education, the Department of Mental Health and Department of Developmental Services have no plans for a large-scale conversion to solar heating in their hospitals. The Department of Mental Health has a solar water system at one hospital (Stockton) and has plans for cogeneration of steam heat in at least two other facilities in the near future. In addition, the department's headquarters in Sacramento will move in 1981 into an energy-efficient building with solar space and water heating. Because of these indicative beginnings, a potential market for solar panels within the two health departments seems to exist, particularly in the event a solar panel assembly industry is undertaken in the state prisons. Therefore, an estimate has been made of solar panel requirements for these two departments. As shown in Table 12, the total market would be ~4 million ft^2 for all 11 hospitals, representing an estimated sales volume of $7.1 million at $18 per ft^2.

Department of Corrections

As with the departments of Mental Health and Developmental Services, the DOC has no near-term plans to procure solar heating systems for its facilities. Allocation for solar installations has not been included in the budgets for the 1981 or 1982 funding years. Unlike the other two departments, however, the DOC may have solar installations without procurement.

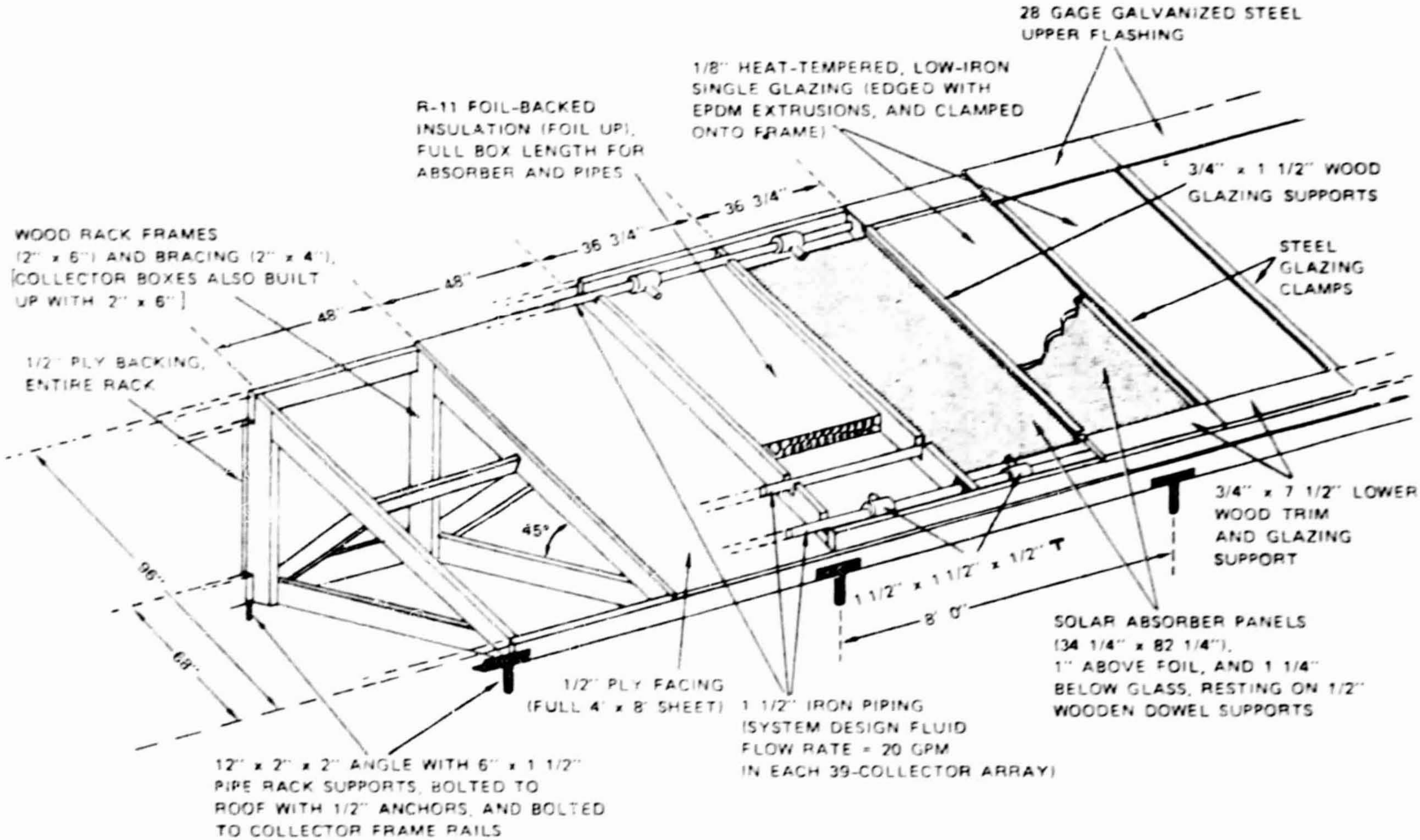


FIGURE 9 SOLAR SYSTEM USED AT SAN JOSE STATE

Table 12

POTENTIAL SOLAR PANEL MARKET FOR CALIFORNIA STATE DEPARTMENT OF MENTAL HEALTH AND DEPARTMENT OF DEVELOPMENTAL SERVICES

Hospital	Number of Beds*	Estimated Requirements (ft^2)	Estimated Dollar Sales Volume (millions)†
Agnews	1,457	37,000	660,000
Atascadero	1,263	30,000	550,000
Camarillo	1,673	40,000	720,000
Fairview	1,691	40,000	730,000
Metropolitan	1,372	33,000	590,000
Napa	2,206	44,000	780,000
Pacific	1,902	46,000	820,000
Patton	1,425	27,000	490,000
Porterville	2,079	50,000	900,000
Sonoma	1,965	47,000	850,000
Stockton	728	2,000	40,000
Total	17,761	396,000	7,130,000

*Based on 1980 statistics supplied by the two departments.

†At $\$18/ft^2$ in 1980 dollars.

Source: SRI International

Within the Correctional Industries, a test facility for solar panels is operated by inmates. Private industries submit their panels for qualification testing according to state specifications. Following the tests, the DOC may accept these panels either as partial payment for the tests or as a donation.

A potential market for the DOC has been included in this analysis in that it is a 10-year forecast. Instead of the market volume of 0.59 million ft^2 shown in Table 13, however, an estimate of less than 0.5 million ft^2 for the DOC has been included in the state agency market forecast to allow for donated systems.

The Department of Transportation

The California State Department of Transportation (DOT) has an active energy conservation program, including conversion to solar energy. During 1979, solar hot-water systems have been installed at 11 maintenance stations, six state-owned homes for maintenance crews, and two asphalt tanks for the storage of paving material. Solar space heating systems have been installed at three maintenance stations and one large office building. Plans for 1981 include solar hot-water systems for three roadside rest stops (primarily for floor heating as a preventative against pipes cracking due to freezing water) and solar space heating for the tollbooths at the new Dumbarton Bridge. The total State DOT solar panel market for the 1979 through 1982 period is expected to be about 2,800 ft^2.

Plans for 1983 through 1985, which have not been formalized, vary among sources of information. The Office of Planning expects a conversion to solar energy at all 63 maintenance stations (see Table 14), some office buildings, and all new constructions. The Office of Resource Conservation near-future forecast anticipates a conversion to solar energy, however, only as maintenance stations are modified or newly constructed; full-scale conversion will be considered after life-cycle savings on existing systems have been determined. Both offices agree that roadside rest stations will not be equipped with solar energy systems, except in areas where the cracking of water pipes due to freezing is a problem.

Summary

The total market for solar panels for use at facilities of the five State of California departments discussed here would be 3 to 4 million ft^2. Most of these panels (66%) would be used for student residences and swimming pools within the college/university system. At \$18 per ft^2, the dollar value to the industry would be between \$5.4 and \$7.2 million per year for 10 years.

Table 13

POTENTIAL SOLAR COLLECTOR MARKET
FOR THE CALIFORNIA STATE DEPARTMENT OF CORRECTIONS

Correctional Institution	Design Capacity (No. of inmates)	Required Solar Panels (million ft^2)*	Potential Dollar Sales Volume (millions)
Chino	2,634	0.06	1.1
Tehachapi	1,177	0.03	0.5
San Luis Obispo	2,559	0.06	1.1
Soledad	2,981	0.07	1.3
San Quentin	2,686	0.06	1.1
Tracy	1,523	0.04	0.7
Jamestown	2,364	0.06	1.1
Vacaville	1,959	0.05	0.9
Folsom	1,778	0.04	0.7
Susanville	1,224	0.03	0.5
Corona	1,578	0.04	0.7
Frontera	930	0.02	0.4
Conservation Camps (19)	1,140	0.03	0.5
Total	24,326	0.59†	10.6

*Based on 24 ft^2 per inmate; $18 per ft^2.

†To allow for donated systems to the DOC, a market volume of 0.50 million ft^2 is estimated, instead of 0.59 million ft^2.

Source: SRI International

Table 14

SOLAR PANEL MARKET FORECAST
FOR THE CALIFORNIA STATE DEPARTMENT OF TRANSPORTATION

District	Number of Maintenance Stations	Solar Panel Requirements (ft^2)*
1, Eureka	5	640
2, Redding	6	702
3, Marysville	7	766
4, San Francisco	11	1,024
5, San Luis Obispo	1	384
6, Fresno	3	512
7, Los Angeles	9	894
8, San Bernardino	6	702
9, Bishop	3	512
10, Stockton	7	766
11, San Diego	5	640
Subtotal	63	7,542
All districts (homes for maintenance crews)	50	3,840
Total	113	11,382†

*Based on 64 ft^2 per station for water heating and 384 ft^2 for space heating (1 station each district).

†This total equals 0.01 million ft^2.

Source: SRI International

Market Assessment by Solar Panel Manufacturers in California

As indicated in Section III, SRI surveyed 21 solar panel manufacturers representing a statistically significant sample of California manufacturers of approximately 10%. Information elicited in the survey included their assessments of the current and future markets as applied to their own companies. These 21 California companies accounted for 26% of U.S. total solar panel sales in 1978 and are expected to maintain California's leading position in solar sales although the percentage may decrease.

According to a majority of the California manufacturers surveyed, the current market consists primarily of personalized services to residential customers for solar water-heating systems (home or pool or both). Other important markets today include private schools (water heating for pools and buildings), municipalities (pools), and progressive businesses (industrial wash). An example of an industrial application is in the Campbell Soup Company's Sacramento, California, plant, where solar-heated water washes the soup cans.

Most of these solar panel manufacturers appeared to be earning a small profit in today's marketplace. A few admitted to less-than-profitable businesses now, but were investing in the future--expecting a sizable market demand in the 1980s. Several others claimed large profits and 3-month order backlogs. Although sales increases of 200% per year were not uncommon in 1978 and 1979, sales volumes were still modest.

All 21 solar panel manufacturers were optimistic about the future. Expectations for the 1980s include:

- An expansion of existing solar water-heating systems to accommodate space heating and air conditioning.
- Increases of 10% to 50% or more per year in residential water-heating sales volumes.
- A sizable industrial/commercial market to begin early in the decade, with 20% per year increases.
- A small but steady municipal market.

The 21 manufacturers omitted sales to state government agencies from the market expectations. One manufacturer's representative commented that he avoids state and federal government business because of the high R&D costs that it usually entails.

Thus, a solar panel market of 7.7 million ft^2 in 1979 might increase to 57.4 million ft^2 by 1989: 39.7 million ft^2 for residential hot-water systems (an increase of 20% per year); 6.0 million ft^2 for expansion of existing residential systems to accommodate space heating (5% of hot-water systems × 3 for requisite additional panels); 5.9 million ft^2 for industrial/commercial hot-water systems (an increase of 20% per year); 0.9 million ft^2 for industrial/commercial space heating (5% of hot-water systems × 3 for additional panels); 4.4 million ft^2 for municipal government systems (10% per year increases); and 0.5 million ft^2 for other applications (10% per year increases). See Table 15 for a summary of these forecasts.

Table 15

CALIFORNIA MANUFACTURERS' 10-YEAR FORECAST

	1979 (million ft^2)	1979-1989 (million ft^2)
Residential hot-water systems	5.2	39.7
Residential space systems	--	6.0
Industrial hot-water systems	0.8	5.9
Industrial space systems	--	0.9
Government	1.5	4.4
Other	0.2	0.5
Total	7.7	57.4

Note: Based on a sample of 21 manufacturers.

Source: SRI International

VII COST/BENEFIT ANALYSIS

Conventional Versus Solar Energy Costs

The most critical variable to the cost/benefit analysis is the fuel cost and its escalation rate. For example, in 1979 electricity from Pacific Gas and Electric Company was priced at $12.25 per million Btu, which included the 95% end-use efficiency for electric water heating. The annual escalation rates used were 0% and 2% above inflation (6%). The natural gas base rate was $4.18 per million Btu, including a 60% end-use efficiency. According to California Public Utilities Commission, the rates for all major utility companies in California were as follows in 1979:

	1979 Price ($/million Btu)	Annual Escalation Rate (percent)
Pacific Gas and Electric Co. (PG&E)		
Electricity	12.25	0-2
Gas	4.18	2-3
Southern California Edison (SCE)	16.58	2-3
LA Department of Water & Power (LADWP)	14.33	2-3
Southern California Gas Co. (SCG)	4.18	5-6
San Diego Gas and Electric Co. (SDG&E)		
Electricity	15.15	1-3
Gas	4.55	5-6

The results of a study done by the Solar Business Office of California indicate that the cost of solar water heating is "fully competitive with the cost of electric water heating, and in many cases is competitive with the cost of natural gas for single-family residential applications throughout the State of California." Solar water heating for multifamily and retrofit cases is also competitive with conventional energy sources, but to a smaller extent. In many cases, solar water heating offers a high rate of return on the consumer's investment. Moreover, an investment in a solar water heater, which can return 10% to 20% or more per year on the net investment (after tax credits) and offers tax-free savings, may be an attractive incentive to households.

As noted earlier, solar water-heating costs are lower than those for heating water with electricity. The delivered price for electricity runs about 30% to 40% more than that for solar energy for the life of a system (20 to 30 years). The rate of return on a solar investment (defined here as the 10% down payment), versus the cost of electricity for the same load demand, ranges from an average of 55% in Oakland to 94% in San Diego. According to the Solar Business Office, a majority of the solar installations in San Diego exceeded a 100% return on the investment. A solar energy versus electric power cost comparison (in kilowatt-hours) by the California Energy Commission (EC) and the Public Utilities Commission (PUC) is provided in Figure 10.

Thus, compared with the figures from the Solar Business Office, the cost of solar would be $0.035 per kilowatt-hour over the entire period. Electricity would increase from about $0.049 in 1979 to $0.065 to $0.075 in 1985, assuming 5% to 7% annual increases.

The results of a comparison of solar with natural gas may also be attractive. For most cases in Northern California, solar energy is not competitive with the current average cost of natural gas. PG&E's lower rates and smaller projected price escalation, combined with only average solar efficiency contribution in most areas, make cost-effectiveness possible for only a few of the cases in Northern California. However, Southern California's higher fuel escalation rates and a greater annual solar efficiency enable solar energy to compete with natural gas in many cases. The rate of return was as high as 15% in this comparison. A solar energy versus gas cost (per therm) comparison by the California EC and PUC is provided as Figure 11. According to the two California commissions, the cost for solar energy (i.e., the initial cost spread over 10 years) would be equivalent to $0.375 (in 1979 dollars) per therm of natural gas compared with $0.375 to $0.475 for natural gas in 1979 and $0.60 to $0.70 in 1985, assuming a 7% annual increase in the cost of gas.

The PUC is considering the establishment of "off-peak" rates for electricity. This practice would further enhance the cost-competitiveness of solar water heating. Under this system,

> A customer who uses electricity to back up a solar system would charge the system during off-peak hours (7 p.m. to 11 a.m.) and would pay a lower rate. The proposed rates for electricity would be about one-third the price currently being charged (or about $4.50 per million Btu).*

If this proposal is approved, solar water heating would compete even more effectively with natural gas throughout the state. Table 16 displays what the average cost for each fuel source would be over a 20-year period, by city, and shows the impact that "off-peak" rates would have. Figures 12 and 13 provide a 30-year (expected life of a solar system) cost comparison of conventional and solar energy sources in selected sites in Northern and Southern California. These are conservative

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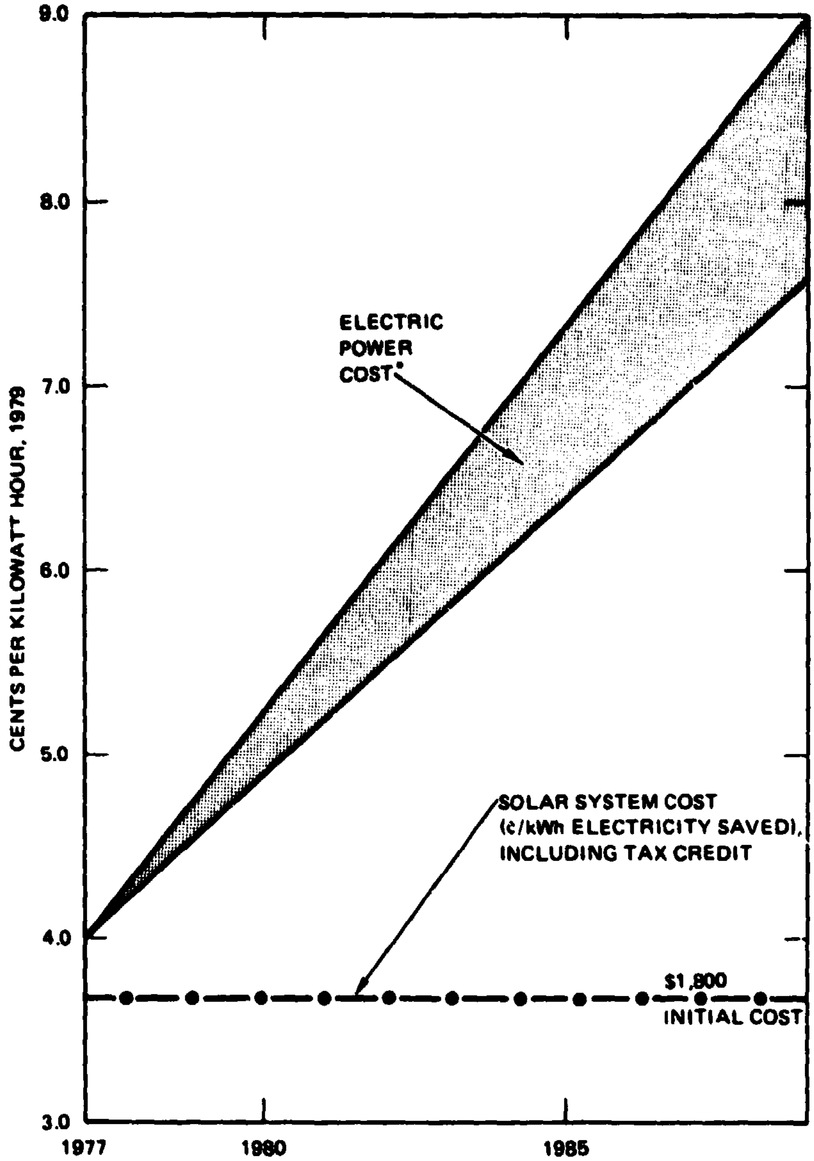
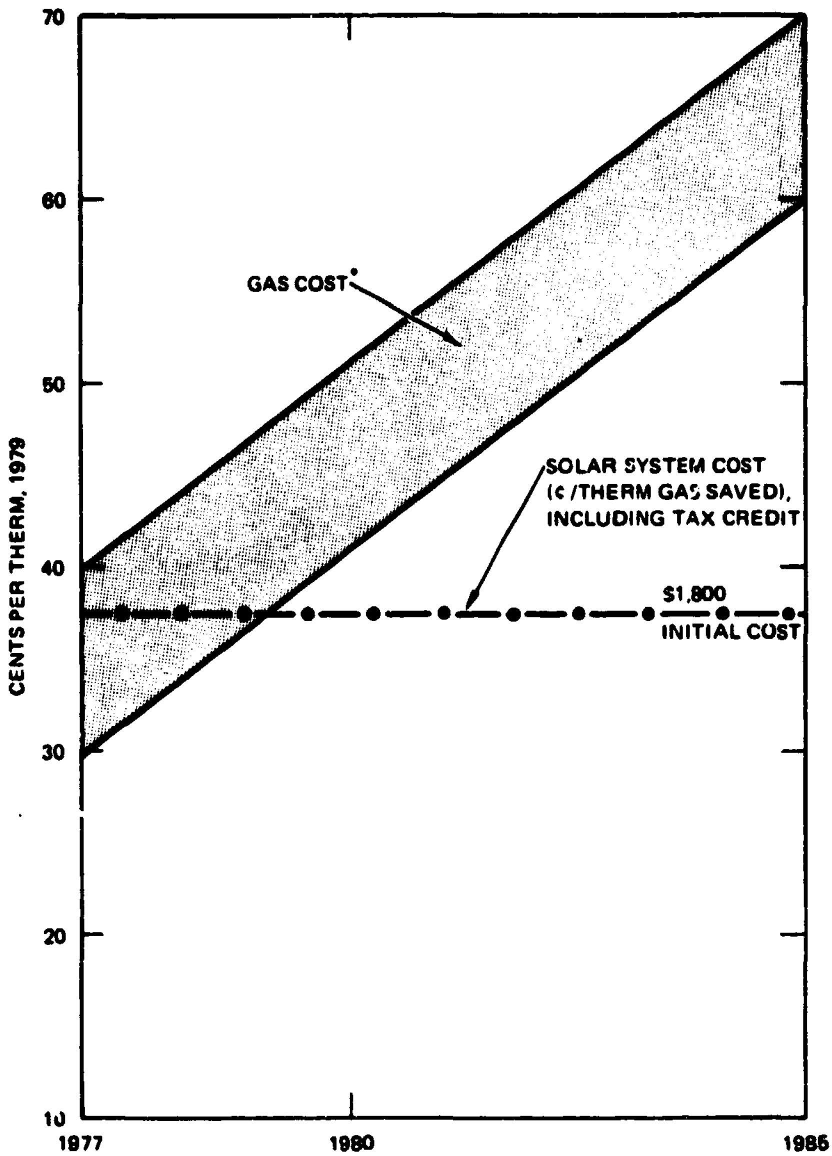
*Johnson, Darryl, "The Economic Evaluation of Solar Thermal Technologies: A Benefit Cost Analysis of Residential Thermal Applications," California Energy Commission, Alternatives Division, Solar Energy Office, April 1978.



*Cost for SCE and SDG&E.

SOURCE: California Energy Commission and Public Utilities Commission

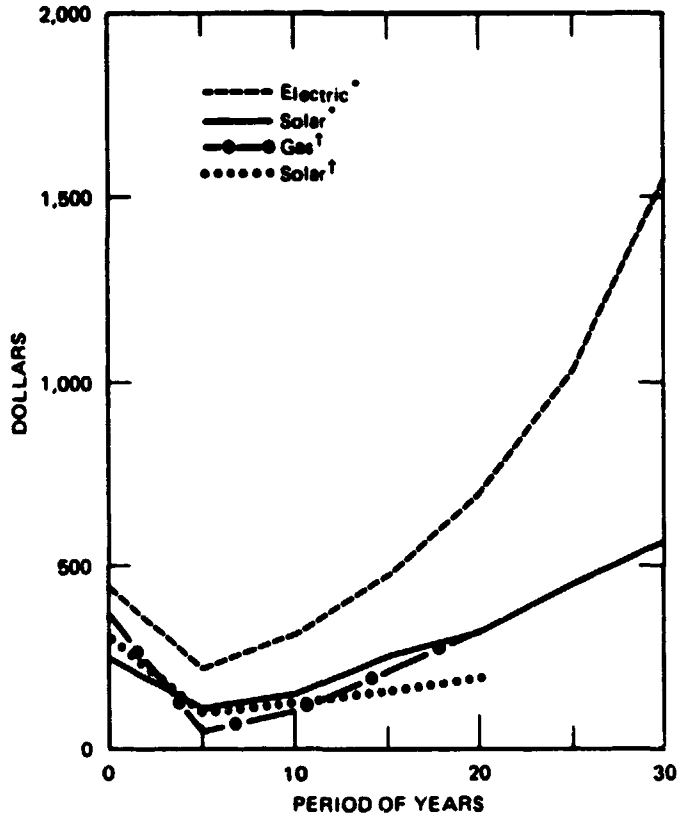
FIGURE 10 COMPARISON OF SOLAR ENERGY AND ELECTRIC POWER COSTS



*Cost for SCG and SDG&E (includes 60% efficiency).

SOURCE: California Energy Commission and Public Utilities Commission

FIGURE 11 COMPARISON OF SOLAR ENERGY AND NATURAL GAS COSTS

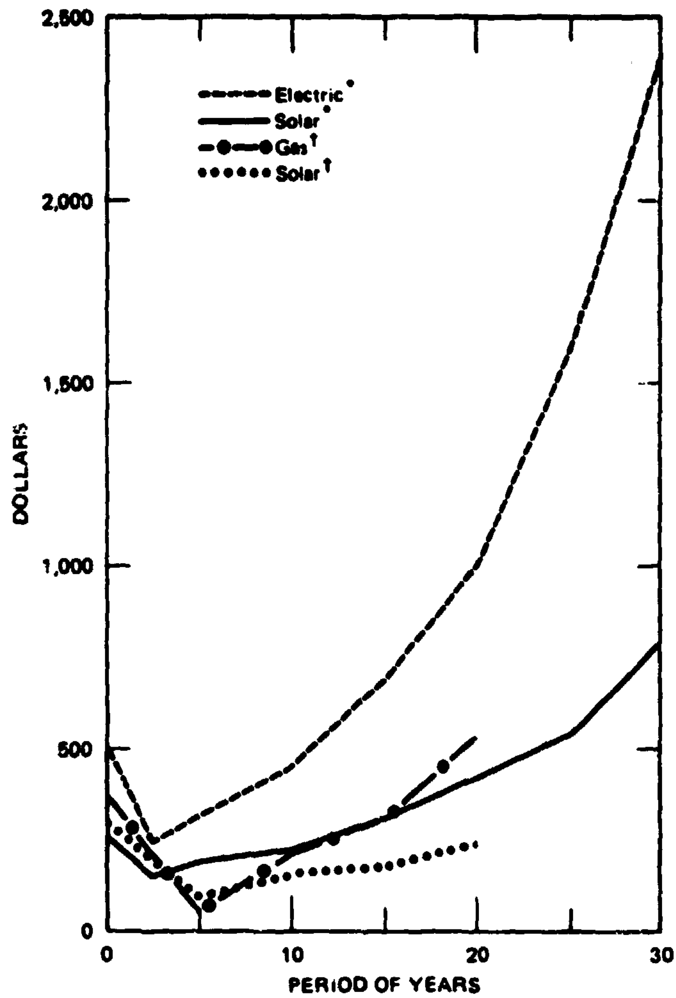


*Electric Versus Solar.

†Gas Versus Solar.

SOURCE: The Solar Business Office, 1979

FIGURE 12 ANNUAL COST ESTIMATES OF WATER HEATING BY GAS, ELECTRICITY, AND SOLAR IN DAVIS, CALIFORNIA



*Electric Versus Solar.
†Gas Versus Solar.

SOURCE: The Solar Business Office, 1979

FIGURE 13 ANNUAL COST ESTIMATES OF WATER HEATING BY GAS, ELECTRICITY, AND SOLAR IN SAN DIEGO, CALIFORNIA forecasts in light of recent energy events, especially considering PUC staff forecasts of a 90% rise in natural gas costs over the next 6 years.

Table 16

AVERAGE WATER-HEATING COSTS FOR 20-YEAR PERIOD AT END-USE EFFICIENCY (1979 Dollars/MMBTU)

	Electricity	Solar with Electric Backup	Natural Gas	Solar with Gas Backup	Solar with Off-Peak Electric
Davis	10.15	6.65	4.25	4.90	4.75
San Rafael	10.15	6.71	4.25	4.93	4.79
Oakland	10.15	6.93	4.25	5.01	4.83
San Jose	10.15	6.52	4.25	4.86	4.71
Fresno	10.15	6.28	4.25	4.77	4.63
Bakersfield	10.15	6.40	4.25	4.82	4.68
Santa Barbara	14.58	6.31	5.27	4.66	4.60
Santa Maria	10.15	5.63	4.25	4.52	4.43
Riverside	14.58	7.23	5.27	4.88	4.55
Los Angeles	12.70	7.13	5.27	5.10	4.94
La Jolla	13.39	7.29	5.68	5.20	5.01
San Diego	13.39	6.05	5.68	4.72	4.55

Assumptions and notes:

1. \$200 water heater on conventional systems.
2. 60-ft^2 solar system.
3. \$2,000 installed cost of solar water heater; uses 55% tax credit.
4. 10% interest on loan, 10% down payment.
5. 20-year loan.
6. End-use efficiency is 60% for gas and 95% for electricity.
7. Off-peak rates: PG&E = \$3.88; SDG&E = \$5.05; LADWP = \$4.77; SCE = \$5.52.
8. MMBTU = 1,000,000 Btu (or 10 therms).

Sources: California Energy Commission, Public Utilities Commission

Residential Cost/Benefit Analysis

A report by the California EC* discusses the costs and benefits of a residential solar energy system. The primary benefit is the monetary savings--the 50% to 80% reductions in household payments for conventional fuels. For a family of four, with an average fuel bill of $50 per month in 1979 ($10.50 for water heating), the savings would range from $300 to $480 (50% to 80%) per year for a full system or about $101 to $113 per year for a water-heating system (80% to 90% efficient).

The costs for a solar energy system are dominated by the initial cost of the equipment and installation. In California, however, 55% of this cost may be deducted from the property owner's income tax (California State Assembly Bill 1-58). Thus, the first-year (1980) cost for a solar water-heating system would be $1,700 for equipment (Table 17) plus $400 for installation, minus a $1,155 tax credit, and about $109 for fuel savings for water heating (based on $10.50 per month fuel bills for conventional water heating with 80% efficiency), or $836.

Costs	Benefits
1,700 equipment	1,155 tax credit
400 installation	109 fuel savings
2,100	1,264

Table 17

COST OF A TYPICAL SOLAR DOMESTIC WATER-HEATING SYSTEM--UNINSTALLED (In Dollars)

	Cost*
Two collectors, flat plate (48 ft^2 total)	1,000
Storage tank (65 gal)	350
Pump, valves, piping, etc.	350
Total	1,700

*Based on 1979 prices.

Source: American Solar King

*Johnson, Darryl, "The Economic Evaluation of Solar Thermal Technologies: A Benefit Cost Analysis of Residential Thermal Applications," California Energy Commission, Alternatives Division, Solar Energy Office, April 1978.

Fuel savings in the next 6 years would almost eradicate the first-year cost. In each subsequent year, a savings of $118 to $218 would be realized if costs for conventional fuels continue to rise at 8%. (See Table 18 and Figure 14.) Notice, too, that the first-year costs could be negative: a 20% downpayment of $420 plus a loan payment of about $265 for a total cost of about $685 compared with a tax credit of $1,155 and fuel saving of $109 for a total of $1,264. That is, the property owner could have a substantial fund of $579.

Costs	Benefits
420 equipment 20% down-payment	1,155 tax credit
265 loan payment	109 fuel savings
685	1,264

Table 18

RESIDENTIAL COST/SAVINGS FOR SOLAR ENERGY WATER HEATING

Cost (Present Value)	Ten-Year Savings at 80% Efficiencies* (Present Value)
945†	1,090

Note: Based on $10.50 per month conventional fuel bills in 1978 for water heating for a family of three or four.

*Built-in inflation of 6% + 2% annual escalation rate.

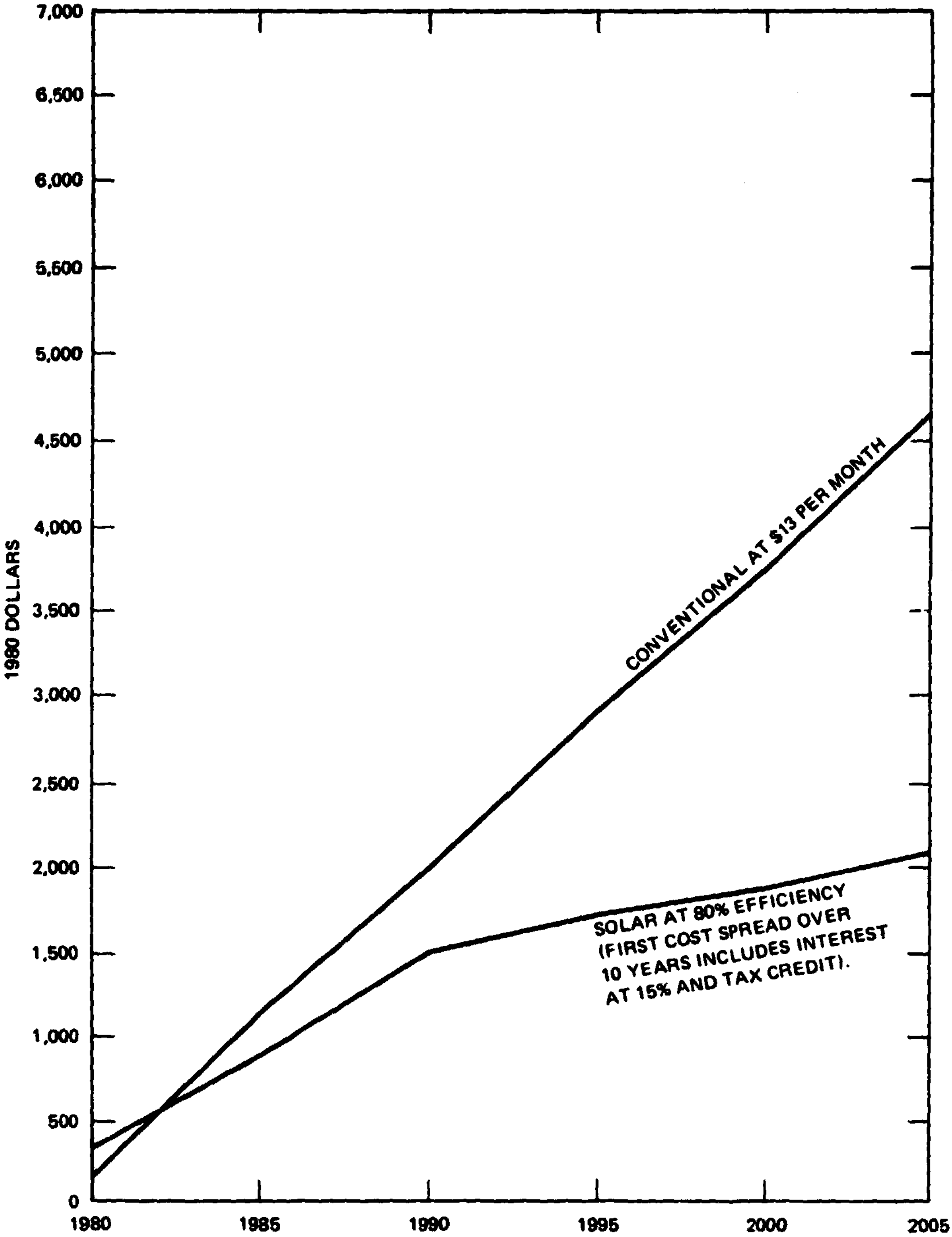
†This figure is the difference of the cost of the solar water-heating system and the tax credit and fuel savings: $2,100-$1,155 = $945.

Source: SRI International

In addition, PG&E offers contractors/builders incentives of $500 to $1,000 per residential construction if energy conservation qualifications are met. These qualifications include the installation of a solar system that provides 50% to 75% of energy needs. Furthermore, PG&E will provide, free of charge, auditors to analyze customers' homes to determine the cost-effectiveness of installing a solar system.

California State Agency Cost/Benefit Analysis

If 80% efficiencies are assumed for solar water-heating systems, the savings in 1979 would be $22.50 per person. Utility rates in 1979 exceeded



SOURCE: SRI International

FIGURE 14 COST COMPARISON OF SOLAR VERSUS CONVENTIONAL WATER HEATING FOR AVERAGE FAMILY IN CALIFORNIA inflation by approximately 2%. If this trend continues and if the inflation rate stabilizes at about 6%, fuel savings would reach $381 per person in 10 years. These savings are based on average commercial rates for gas and electricity obtained from PG&E.

At 24 ft^2 of solar collector per person (the size recommended by about 80% of the manufacturers contacted by SRI), the cost per person for a commercial system at $18/$ft^2$ average plus pump, pipe, tank, and installation costs of $175 would be $607--$226 more than the 10-year fuel savings. (The state does not benefit from the tax incentive.) The system would not pay for itself until year 14.

The installation of solar panels assembled as a prison industry should result in savings in considerably less time. Discussions with staff members of the Executive Office of the DOC and Growlersburg Conservation Camp revealed that a price of $10/$ft^2$ or less installed, is possible if panels were machine-assembled rather than hand-assembled as is the current practice. At 24 ft^2 per person the total cost would be $240 plus about $175 for additional equipment; this amount could be repaid in about 12 years.

The solar panels that are being produced currently at the Growlersburg Conservation Camp in Georgetown, California are made by hand at a rate of about 2.5 panels per day (with a 200-panel-per-year limit). Materials include a fiber glass frame, a glaze of fiber glass impregnated sheeting, an all-copper plate, and copper tubing. The materials cost for each panel is about $75. Production requires approximately 12.5 man-hours of labor per panel. Panels are available for $10/$ft^2$. That is, each panel, measuring 3 x 10 ft, costs $300. Included in this price is the cost for inmate training. (The training program at Growlersburg is intensive and emphasizes high-quality workmanship for both production and installation.) The Growlersburg price falls within the range of private industry, albeit at the lower end.

According to Growlersburg staff members, the solar panel price could be reduced further if production facilities were mechanized. Needed would be a press to provide grooves for the tubing, another press to insert the tubing, a welder to secure the heads to the tubing, and a die or two for a capital investment of about $100,000. Spray equipment would be required for coating the frame if extruded aluminum or steel were used instead of fiber glass. The combined labor-plus-overhead cost (12.5 hr at about $10 to $15 per hr) could be reduced by 50% or more. A panel price of less than $200 (about $6/$ft^2$), or $144 per person, would then be possible and the system (about $319 per person) would pay for itself in 9 years.

It should be noted that by 1993 the state could realize savings in the neighborhood of $6.7 million per year ($67 fuel savings per person in 1993 dollars; 100,000 persons) regardless of the source of the solar system. That is, all systems, whether $6, $10, or $18/$ft^2$, could have paid for themselves by 1993, after which a $6.7 million or more annual saving would be realized. Additional savings may result from reduced prison and welfare costs.

However, if comparisons are limited to present value costs and the present value of benefits, given steady utility costs, the calculations indicate higher 12-year costs for solar energy than for conventional energy even at $\$6/ft^2$. (See Table 19.)

Table 19

COST COMPARISON OF SOLAR AND CONVENTIONAL WATER HEATING FOR CALIFORNIA STATE AGENCIES

Annual Cost per Person for Solar Energy* (dollars)			Annual Cost per Person Conventional Energy*† (dollars)
At $\$6/ft^2$ of solar panels	At $\$10/ft^2$ of solar panels	At $\$18/ft^2$ of solar panels	
319	415	612	270

*Efficiencies of 80% are used to facilitate cost correlation. Conventional water-heating costs based on $22.50/person in 1979; solar on 24 ft^2 per person plus other equipment costs.

†Based on a rate 2% above inflation of 6%.

Prison Industries Cost/Benefit Analysis

Potential benefits of solar panel assembly for the DOC prison industries include:

- Job skills development for inmates
- A ready market with state agencies
- Employment for about 50 inmates
- Small capital investment.

The outcomes of an investigation made to determine the reality of these potential benefits are discussed below.

The existing training program at the Growlersburg Conservation Camp has been successful in assisting inmates with job skills development--i.e., skills in solar panel assembly and installation. The training program is described as intensive and designed for product excellence. It is assumed that this training program would continue. Although assembly techniques may change as the industry becomes more mechanized, the installation techniques taught at Growlersburg should be directly applicable in new mechanized operations. All comments made by representatives of the State of California's Department of Forestry, DOC, and Solar Business Office, regarding the inmate training program, were complimentary.

A sizable market for solar panels does exist with the state agencies provided that cost-effectiveness is affirmed. Cost-effectiveness depends in large part on the price of conventional fuel. As discussed earlier, Californians paid an average of $31 per person per year for conventional water heating in 1979. By 1990, at 8% per year rate increases (2% above inflation estimates), the average cost per person for conventional energy sources will be $73.8 per year, with a cumulative (1979-1990) cost of $598. Solar system annual costs per person for water heating would be $319 at $6/ft^2, $415 at $10/ft^2, and $612 at $18/ft^2 (24 ft^2 per person) for 80% or better efficiencies. To facilitate correlation of the solar energy costs with conventional energy costs, 80% efficiencies were applied to both energy source costs. A 10% cost reduction was applied to conventional fuel costs to accommodate average non-residential rates. Thus, the $319, $415, and $612 solar costs per person per year are compared with a 10-year cost of $381 for conventional energy sources (70% of $544).

At approximately 3.4 million ft^2 (the 10-year market, as determined by a survey of five state agencies), employment for 42 inmates could be provided for at least 10 years at a production rate of 32 ft^2 per day per man on the basis of 255 working days. At 64 ft^2 per day per man, employment for only 21 inmates full-time or 42 inmates half-time could be provided. Only by employing inmates on a half-time basis will the work force exceed 50. (See Table 20).

In September 1979, at the invitation of the California State Prison at San Quentin, SRI Team members, the NASA-MSFC Technology Utilization Officer, and an MSFC solar cooling and hot-water equipment specialist inspected the San Quentin compound. The inspection resulted in general agreement on the suitability of San Quentin's physical facilities for the production of solar panels, where an ideal building is available for that purpose.

In addition, the new prison industry would benefit from the extensive experience of NASA's Marshall Space Flight Center, gained through the development and testing of solar systems for more than 25 manufacturers.

Table 20

TEN-YEAR MARKET FORECAST FOR A SOLAR-PANEL PRISON INDUSTRY

Total State Agency Market (ft^2)	Daily Production per Inmate (ft^2)	Years To Meet Market Demand*	Inmates Employed (half-time)
3.4 million†	32	10	42‡
	64	10	42
	64	8	52
	96	8	35
	96	6	46
4.0 million§	32	10	49
	64	10	49
	64	8	62
	96	8	41
	64	6	82
	96	6	55

*Based on 255 working days per year.

†SRI estimate based on survey of five departments of the state.

‡Full-time employment.

§SRI estimate for all departments of the state.

Source: SRI International

BIBLIOGRAPHY

Aitken, Donald W., and David E. Rozell, "Project Sunshower: San Jose State University Dormitory Retrofit to Solar-Assisted Water Heating," San Jose State University, San Jose, CA (1976).

California Parks and Recreation Department, "Statistical Report, Fiscal Year 1976-1977," State of California, Sacramento, CA.

Gierlach, K. A., "Solar Heating Market Survey of Major Home Builders," SRI International, Menlo Park, CA (1979).

Johnson, Darryl, "The Economic Evaluation of Solar Technologies: A Benefit Cost Analysis of Residential Thermal Applications," Alternatives Division--Solar Energy Office, California Energy Commission; Sacramento, CA (April 1978).

Johnson, Darryl, "User's Guide to Solar Finance," California Energy Commission, Sacramento, CA (September 1979).

National Aeronautics and Space Administration, NASA Tech Briefs, Vol. 2, No. 4, Winter 1977.

National Aeronautics and Space Administration, NASA Tech Briefs, Vol. 3, No. 2, Summer 1978.

National Aeronautics and Space Administration, NASA Tech Briefs, Vol. 3, No. 4, Winter 1978.

National Aeronautics and Space Administration, NASA Tech Briefs, Vol. 4, No. 2, Summer 1979.

National Aeronautics and Space Administration, NASA Tech Briefs, Vol. 4, No. 3, Fall 1979.

PG&E, "Plans for 1980 Energy Conservation Activities," presented before Public Utilities Commission, December 1, 1979.

Public Utilities Commission, "Annual Report: 1977-1978 Fiscal Year," State of California, Sacramento, CA (December 1).

U.S. Department of Energy, "Solar Energy: A Status Report," U.S. Government Printing Office, Washington, D.C. (June 1978).

Yudelson, Jerry and Ethan Thorman, "The Benefits of Solar Water Heating In California," Solar Business Office--Business and Transportation Agency, Sacramento, CA (July 1979).

Appendix A

SOLAR HEATING AND COOLING INFORMATION SOURCES

Appendix A

SOLAR HEATING AND COOLING INFORMATION SOURCES

1. National Solar Heating and Cooling Information Center
   P.O. Box 1607
   Rockville, MD 20850

   or call toll-free 800-523-2929.

   - This center can be contacted for information on contracts and grants for both commercial and residential applications of solar heating and cooling.
   - An informative booklet, "Solar Energy and Your Home" (HUD-PBR-183) was designed by HUD to answer some of the most frequently asked questions about how solar energy can be put to work at home. This booklet is available without charge from the Center.

2. Department of Energy
   Technical Information Center
   P.O. Box 62
   Oak Ridge, TN 37830

   No-cost pamphlets available in quantity from TIC include:

SE-101	Solar Energy for Space Heating and Hot Water
SE-102	Non-Technical Summary of Distributed Solar Power Collector Concept
EDM 527	Solar Energy
EDM 816	I've Got a Question About Using Solar Energy

Periodicals:

- "Applied Solar Energy," Geliotekhnika (a cover-to-cover translation of this Russian Journal on solar energy research), Allerton Press, Inc., 150 Fifth Avenue, New York, NY, 10011. Annual subscription (6 issues) $110.00. May be available at larger libraries/universities.
- "Solar Age," Solar Vision, Inc., 200 East Main Street, Port Jervis, NY, 12771. Annual subscription $20, monthly.
- Solar Engineering Magazine, Solar Engineering Publishers, Inc., 8435 N. Stemmons Freeway, Suite 880, Dallas, TX, 75247. Annual subscription $15, monthly. The official publication of the Solar Energy Industries Association.

- "Solar Energy, The Journal of Solar Energy Science and Technology," Journal of the International Solar Energy Society. Annual subscription $65. Subscriptions to the Subscription Fulfillment Manager, Headinton Hill Hall, Oxford OX3 OBW, England.
- "Sunworld," published quarterly by the International Solar Energy Society. Annual subscription $12. Editorial and Subscription Offices, 320 Vassar Avenue, Berkeley, CA, 94708.

Books:

- Solar Energy--Technology and Application
  J. Richard Williams
  Ann Arbor Science
  P.O. Box 1425
  Ann Arbor, Michigan — $4.50
- Solar Heating & Cooling--Engineering, Practical Design, and Economics
  Jan F. Kreider and Frank Kreith
  Scripta Book Company
  Washington, D.C. — $15.20
- Solar Energy--A Practical Guide
  Daniel H. Lufkin
  303 West College Terrace
  Frederick, Maryland 21701 — $10.50
- A Floridian's Guide to Solar Energy
  Robert J. Pozzo
  Florida Solar Energy Center
  300 State Road 401
  Cape Canaveral, Florida 32920 — $1.50

Note: 1978 prices.

Appendix B

REPRESENTATIVE NASA SOLAR PANEL TECHNOLOGIES

All-Glass Solar Collector

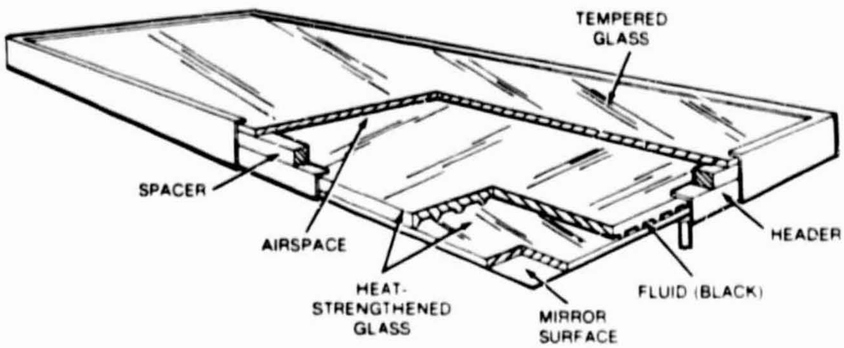
Maintenance-free
solar collector

Marshall Space Flight Center, Alabama

Conventional solar collectors incorporate a number of metal components. Much of the collector is metal tubing carrying the heated fluid. The metal is relatively expensive and may corrode with time.

A proposed alternative is an all-glass solar collector. The collector is designed for high efficiency, and because of its all-glass structure, it is virtually maintenance-free.

The proposed configuration as shown in the illustration is made from several plates of glass stacked on top of each other. The top plate is tempered glass, which admits incoming solar radiation. This glass has been treated to resist breakage from various wind-driven objects and to resist the effects of heat. Directly underneath is air that acts as a thermal barrier, preventing loss of the collected heat back to the environment. Below this space are two layers of heat-strengthened glass. The area between the two layers is grooved. A film of black solar fluid flows through the grooved area and is heated directly by solar radiation. A mirrored surface below the fluid reflects any lost energy back to the fluid.



An **All-Glass Solar Collector** is corrosion-free and more economical without conventional fluid-carrying metal tubes. It utilizes black fluid to absorb solar heat. A mirrored surface on the bottom reflects any heat lost back to the fluid.

The advantages of this type of construction include:

a. A practically maintenance-free collector without corrosion problems,
b. Reduced costs due to glass instead of metal,
c. The use of efficient black fluid to collect solar heat, and
d. The use of mirrored surface to return any lost energy back to the fluid.

This work was done by John P. Wisnewski of PPG Industries, Inc., for **Marshall Space Flight Center.** *No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page A5]. Refer to MFS-23870.

"Tubeless" Flat-Plate Solar Collector

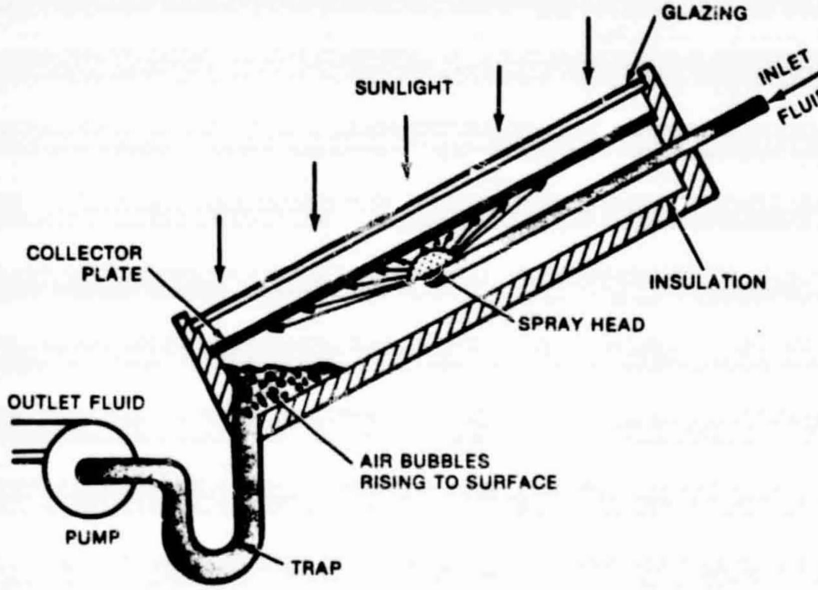
A proposed solar collector could collect solar energy efficiently without metal tubing.

Caltech/JPL, Pasadena, California

Despite the large number of variations of the conventional flat-plate solar collector that have evolved recently, none are yet sufficiently cost-effective for widespread home use. This is largely due to the extensive use of formed metal parts for the collector plates and for the tubing, channeling, or the equivalent that circulate the energy-collection fluid (usually water) within the collector.

In a proposed design, heat would be removed from the collector plate effectively by bringing the collector fluid into direct contact with the absorber plate without the use of tubing or channeling. As can be seen in the figure, this could be accomplished by spraying the collector fluid onto the undersurface of the collector plate. This would produce a convective heat-transfer coefficient large enough so that only minimal spatial temperature variations would occur in the plane of the absorber. Consequently, the requirement for high in-plane thermal conductance, a necessity for collectors with absorbers that must conduct absorbed solar energy to attached fluid conduits, would be eliminated. Low-cost materials, summarily overlooked in the past because of low thermal conductivity (e.g., plastics), could thus be utilized in this novel design.

The heated fluid collects in a sump from which it is pumped through the system for space heating and/or domestic hot-water supply. The collector structure could employ the usual insulation and double glazing to reduce heat losses.



Efficient Heat Transfer Without Pipes in a solar-energy collector might be possible by spraying the heat-transfer fluid against the underside of the collector plate. A single spray head or an array of spray heads might be used. The chief advantage of this approach would be the relaxation of materials requirements, as high thermal conductivity of the absorber plate material is no longer a critical selection parameter.

The primary cost savings with this approach would be through the greater latitude possible in materials selection. The collector plate might be made of plastic, glass, or metal; however, one advantage in using plastics for the portions of the structure in contact with the absorber fluid is that the compatibility problems encountered with metals used in conventional structures may be avoided. In addition, plastics are less likely to be damaged should the fluid accidentally freeze. Of course additional costs would be incurred through the use of a spray nozzle and the required pump work, and there may be maintenance requirements to keep the spray orifices open. A more thorough evaluation of this type of approach would be required to determine its efficiency and cost-effectiveness.

This work was done by Burton Zeldin of **Caltech/JPL.** *No further documentation is available.*
NPO-13897

Performance After Weathering of a Liquid Solar Collector

No changes were measured after 11-1/2 months of weathering.

The liquid solar collector described in "Performance Evaluation of a Liquid Solar Collector" (MFS-23931) on page 216 of *NASA Tech Briefs,* Vol. 3, No. 2, has been retested after long-term exposure to natural weathering. As summarized in a report that has been made available, weathering caused no detectable degradation in collector performance and no visible deterioration in its appearance. Supporting data and a comparison of pretest and posttest efficiencies are included.

The single-glazed flat-plate collector was held stagnant (no flow) for approximately 4 months on the weathering test stand at Marshall Space Flight Center. It was then held intermittently stagnant and active over a 5-month period. The final weathering was for 2-1/2 months.

Collector efficiency was measured (on a solar simulator) at a flow rate of 0.57 gal/min (2.19 l/min) for inlet temperatures of 0°, 25°, 50°, and 100° F (0°, 14°, 28°, and 56° C) above ambient. The solar flux was 300 Btu/h-ft^2 (3.4×10^6 J/h-m^2), and windspeed was 7.5 mi/h (12 km/h). Within experimental error, the posttest collector-efficiency curve was unchanged from the pretest curve.

This work was done by the Solar Energy Systems Division of Wyle Laboratories for **Marshall Space Flight Center.** *To obtain a copy of the report, "Long Term Weathering Effects on The Thermal Performance of The Sunworks [Liquid] Solar Collector."*

Design Review of a Liquid Solar Collector

Problems encountered in operational systems are analyzed.

The procedures, results, and recommendations of an in-depth analysis of problems with the liquid-filled version of the concentric-tube solar collector (see preceding articles) are documented in a new report. The problems related to the loss of vacuum and/or violent fracture of the collector elements, fluid leakage, freezing, flow anomalies, manifold damage, and other component failures.

The analysis showed that the basic collector design is sound; most problems could be traced to defective equipment or improper operating procedures. It is recommended that care be taken to avoid these problems in present and near-term applications. A long-term performance evaluation and improved materials in critical components would reduce problems in future installations.

In a review of operating procedures and materials at nine existing sites, it was discovered that system failures were preceded or accompanied by boilout, freezeup, or hot fill (filling of an already-heated collector). It is recommended that users prevent these occurences by using correct operating procedures.

Tests on a solar simulator showed that an unscratched stagnant collector tube does not fail in a 2-day boilout during which it reaches temperatures above 600° F (315° C). A "good" tube will fail, however, if hot-filled; and violent fractures were observed in previously scratched tubes. Thus, tubes should be proof-tested before installation; and careful operating procedures should be used to prevent accidental boilout, hot fills, stagnation, and freezeup. Assembled arrays should be leak-tested before use.

Two aspects of collector design were reviewed: (1) the tube alinement tolerances in the manifold and (2) the tube structural strength. Alinement tolerances in the manifold were considered adequate to prevent binding and breakage. A simplified finite-element strength analysis indicates that the tube strength is adequate, **however, a more refined analysis that would account for temperature effects and residual stresses and defects is recommended.**

This work was done by Bernhard L. Wiesenmaier of **Marshall Space Flight Center.** *To obtain a copy of the report, "Final Report on MSFC Assessment of Owens-Illinois Sunpack™ Collector Problems,"*

Performance of Black-Nickel and Black-Chrome Solar Collectors

A comparative study

A new report presents the procedures used and results obtained during tests to determine the comparative efficiency of black-nickel and black-chrome solar-collecting surfaces.

The program evaluated four unique solar collectors, including:
- a black-nickel collector surface with a desiccant drying bed,
- a black-nickel collector surface without a desiccant drying bed,
- a black-chrome collector surface with a desiccant drying bed, and
- a black-chrome collector surface without a desiccant drying bed.

The test program included three distinct phases:
- phase I — initial performance evaluation,
- phase II — natural environmental aging, and
- phase III — post-aging performance evaluation.

The test conditions included seasonal ambient conditions. Phase I testing occurred during the winter months, while phase III occurred during the summer months. Performance evaluation testing occurred only during daylight hours with the solar flux greater than 250 Btu/h-ft^2 (0.019 cal/s-cm^2) for an extended period of time. Results of phase III testing indicated a higher normalized efficiency for black-chrome collector surfaces than for black nickel.

This work was done by R. Losey of Wyle Laboratories for **Marshall Space Flight Center.** *Further information may be found in NASA CR-150497, "Performance Evaluation of Two Black Nickel and Two Black Chrome Solar Collectors."*

Glass Solar Collector — Materials Assessment

Tests to prevent explosive failure under boilout conditions

A comprehensive series of tests has been carried out to evaluate the design, materials, and failure modes of a commercially-available glass solar-collector system. The results of the materials analysis segment of the program are presented in a report that is now available.

The collector has 24 glass tubes manifolded together so that fluid flow is channeled sequentially through each tube. Individual tubes consist of two concentric glass tubes with a hard vacuum in the annular space between them. There is a selective absorber coating, with high solar absorptivity and low emittance, on the outer surface of the inner tube. The vacuum protects the coating from atmospheric degradation and suppresses conductive heat loss. This construction allows the temperature of the inner tube to rise to approximately 650° F (340° C) when the collector is stagnated.

The primary problem investigated in the test program was explosive failure of the collector during boilout. Boilout occurs when the system is collecting solar energy but no fluid is flowing through the tubes. Under these conditions, the pressure can rise above that of the pressure relief valve [approximately 35 psig (2.4×10^5 N/m^2)], venting steam and hot water to the outside.

The report presents data obtained during pressure-testing of the individual tubes and during performance-testing of a complete array of tubes on the Marshall Space Flight Center solar simulator. Other parts of the study investigated the effects of thermal shock, fracture initiation, and residual stresses near seals on the glass tubes. The tube absorber coating, the manifold components, the insulation, and various plastic and rubber components were also evaluated.

It is concluded that proof-testing of the collector tubes prior to their use helps to predict their performance for limited service life. Fracture-mechanics data are desirable for predicting extended service life and establishing a minimum pressure-level requirement.

This work was done by R. L. Nichols of **Marshall Space Flight Center.** *Further information may be found in NASA TM-78163, "Owens-Illinois Liquid Solar Collector Materials Assessment."*

Liquid Solar Collector — Performance Tests

To verify compliance with HUD standards

A 156-page report describes comprehensive performance tests on a commercially-available, flat-plate, liquid solar collector. The tests were initiated to verify that the collector meets U.S. Housing and Urban Development (HUD) Department Standards for "thermal stability." The test program consists of three parts: (1) initial thermal performance; (2) 30-day stagnation; and (3) final thermal performance.

The test item is a modular nonmetallic single-glazed liquid solar collector that is designed for field assembly. It consists of 30 closely spaced elastomeric twin tubes cemented to an insulating base and covered with flexible plastic. The panel is 4 ft (1.2 m) wide by up to 25 ft (7.6 m) long. The length can be selected to meet the requirements of the building in which the system is installed.

The initial thermal performance test consists of four parts:

- *Preconditioning.* The collector is filled with water, and the inlet is sealed. Then the panel is held in a nonoperational stagnation mode in which the water is allowed to evaporate. The stagnant collector is exposed for 3 days to cumulative solar radiation of at least 1,500 Btu/ft^2/day (4.73×10^{-3} cal/cm^2/s).
- *Time Constant.* The transient response of the collector to a step change in insolation is measured.
- *Instantaneous Efficiency.* The collector efficiency is determined as a function of solar radiation flux, ambient temperature, and fluid inlet temperature.
- *Incident-Angle Modifier.* The efficiency is measured for solar radiation incident at 30°, 45°, and 60° with respect to the normal to the collector.

Possible materials or construction problems are identified during the 30-day stagnation exposure tests that follow the initial thermal performance tests. During this period, the stagnant water-filled collector is exposed to 1,500 Btu/ft^2/day solar flux. A 4-hour exposure to 300 Btu/ft^2/h (0.0227 cal/cm^2/s), after boilout of the water, is made at least once. The physical appearance of the collector is monitored, and data on ambient temperature, wind, and precipitation are recorded.

The final thermal performance test differs from the initial test in that there is no preconditioning, no time-constant measurement, and no incident-angle modifier measurement. The efficiency measurements are made at 12 test points instead of the minimum of 16 points in the initial sequence.

A special test of the instantaneous efficiency at four points, with the collector glazing removed, was carried out. This was done to determine indirectly the losses through the cover. [Also see preceding article "Design and Installation of a Flat-Plate Solar Collector (MFS-25010).]

This work was done by Calmac Manufacturing Co. for **Marshall Space Flight Center.** *To obtain a copy of the report, "Certification and Verification for Calmac Flat Plate Solar Collector,"*

Indoor and Outdoor Tests of a Liquid Solar Collector

A comparative thermal-performance study

Two new reports describe thermal-performance data obtained on a double-covered liquid solar collector. One report describes data obtained during outdoor testing, and the other describes indoor test data obtained by using the Marshall Space Flight Center solar simulator. The indoor data were taken to verify the performance of the solar simulator.

The solar collector has a double-glass cover with dimensions 3 by 4 by 0.5 ft (0.91 by 1.2 by 0.152 m); its dry weight is 65 lb (29.4 kg). The iron oxide absorber has an absorbtivity of 0.91, an emissivity of 0.37, and a surface area of 10.23 ft^2 (3.12 m^2).

The outdoor tests checked the thermal performance of the collector at 100°, 150°, and 200° F (37.7°, 65.5°, and 93.3° C) inlet temperature with the flow rate controlled at 120 lb/h (0.015 kg/s). The solar flux was between 190 and 360 Btu/h-ft^2 (0.014 and 0.027 cal/s-cm^2). Parameters such as absorber temperature, flow rate, and wind velocity and direction were recorded and are presented in tables.

The indoor test program obtained thermal performance data under similar conditions for comparison with the data obtained outdoors. The comparison is presented as a graph of collector efficiency versus a normalization parameter that includes the effects of ambient and inlet temperatures and of the incident flux.

This work was done by R. Losey and K. Shih of Wyle Laboratories for **Marshall Space Flight Center.** *Further information may be found in:*

NASA CR-150505, "Thermal Performance of Honeywell Double Covered Solar Collector," and NASA CR-150507, "Verification Test of the MSFC Solar Simulator Using a Honeywell Double-Covered Liquid Solar Collector."

Copies of these reports may be obtained at cost from the New England Research Application Center *[see page A7].*

MFS-23886

Thermal Performance of a Flat-Plate Liquid Solar Collector

Comprehensive tests were carried out in a solar simulator.

A report is available that presents the procedures and results of a program to obtain thermal performance data on a double-covered liquid solar collector. The Marshall Space Flight Center solar simulator was used for the tests.

The device tested is a flat-plate solar collector that uses a liquid heat-transfer medium. The copper absorber plate is 0.021 in. (0.053 cm) in thickness; the absorber surface is 19.74 ft^2 (1.82 m^2); and the overall dimensions of the collector are 3 by 4 ft by 3/4 in. (0.91 by 1.22 m by 1.9 cm). It has a double cover made of tempered glass 1/8 in. (0.318 cm) in thickness. The weight is approximately 130 pounds (58.9 kg).

The thermal performance tests were conducted at inlet temperatures of 100°, 120°, 150°, and 200° F (38°, 49°, 66°, and 93° C) with a controlled liquid-flow rate of 290 pounds per hour (0.036 kg/s) at solar flux levels of 230 and 270 Btu/h-ft^2 (0.017 and 0.020 cal/s-cm^2) with simulated wind conditions of 0, 10, and 13 mi/h (0, 16, and 21 km/h). The test conditions and the thermal performance data obtained during the tests conducted on the simulator are contained in the report.

In addition, a test was carried out to obtain the time constant for the collector with the inlet held at ambient air temperature, the solar flux level at 230 Btu/h-ft^2, and the liquid flow rate at 290 lb/h.

The effect of incident angle on the collector was also tested with a liquid flow rate of 290 lb/h, the inlet temperature controlled to ambient air temperature, and with the collector tilted at 45°, 60°, and 75° with respect to the solar simulator surface.

This work was done by K. Shih of Wyle Laboratories for **Marshall Space Flight Center.** *Further information may be found in NASA CR-150508, "Indoor Test for Thermal Performance Evaluation of Libby-Owens-Ford Solar Collector."*

Corrosion Inhibitors for Solar Heating and Cooling Systems

Tests of several inhibitors under simulated conditions

Several forms of corrosion, including uniform, galvanic, and pitting, can degrade performance and increase the maintenance costs of solar heating and cooling systems. In a recent study carried out for Marshall Space Flight Center, several candidate materials were tested for their ability to limit corrosion under conditions that approximate those found in a typical solar-energy system. The results of the study are available in a new report.

In the test system, a cartridge heater was enclosed in an aluminum test coupon, and the assembly was seated in a glass jacket. During the tests, the cartridge heated the aluminum (which simulates a solar panel), and the aluminum heated a fluid flowing through the glass jacket. A mild-steel coupon in the fluid reservoir represented the steel that is often used for the storage basin in solar heating systems. A copper wire connected the aluminum coupon to the steel to simulate galvanic coupling and copper joints in the plumbing of a solar system. The various inhibitors were added in controlled amounts, and the weights of the test coupons were checked at the end of each test; any loss of weight was attributed to corrosion.

The study included both short- (7-day) and long-term (60-day) tests and an economic analysis of each inhibitor. Several promising additives were found. Of these, sodium chromate at 1,000 parts per million gave the best corrosion protection in both the short- and long-term tests. In the test system, for which the corrosion rate was 6.3 mil/yr (0.16 mm/yr) for aluminum and 22.7 mil/yr (0.58 mm/yr) for steel without the inhibitor, long-term corrosion was only 0.12 mil/yr (0.003 mm/yr) for aluminum and 1.77 mil/yr (0.04 mm/yr) for steel if sodium chromate was added.

In addition to a presentation of the data, the report also includes a discussion of the different forms of corrosion and recommendations for future work.

This work was done by John H. Tabony of Southern University for **Marshall Space Flight Center.** *Further information may be found in NASA CR-150513, "Inhibitor Analysis for A Solar Heating and Cooling System."*

Flat-Plate Solar Collector — Installation Package

Includes installation, operation and maintenance, and repair procedures

The installation package for the air flat-plate solar collector described in the preceding article can be obtained by requesting the report referenced below. The package includes the installation, operation, and maintenance manual for the collector, an analysis of safety hazards, special handling instructions, a materials list, installation drawings, and the warranty and certification statement.

The installation, operation, and maintenance manual includes instructions for roof preparation and for preparing the collector for installation. Checkout procedures are also given. Several pages in the maintenance section are devoted to procedures for major and minor repairs.

This work was done by Life Sciences Engineering for **Marshall Space Flight Center.** *Further information may be found in NASA CR-150536, "Installation Package for Air Flat Plate Collector."*

Design and Installation of a Flat-Plate Solar Collector

Includes information on collector sizing

Performance and installation information for a flat-plate, liquid solar-energy collector is presented in a new report. The single-glazed collector consists of 20 closely-spaced elastomeric twin tubes cemented to an insulating base and covered by flexible plastic. The panel area is selected to meet the requirements of the building in which it is installed; it can be assembled in sizes up to 4 by 25 ft (1.2 by 7.6 m). Several panels can be ganged to make larger sizes.

The collector is designed to meet Housing and Urban Development (HUD) Department standards for home use. Its performance is summarized by the criterion that it collect at least 500 Btu/day/ft^2 (0.00157 cal/s/cm^2) at an inlet fluid temperature of at least 130° F (54.4° C) under the following conditions:

- Tilt angle = 50° with respect to the horizontal.
- Azimuth is due south.
- Ambient temperature = 40° F (4.4° C), average.
- Wind velocity = 600 ft/min (3.05 m/s), average.
- Noon solar flux = 290 Btu/h/ft^2 (0.0219 cal/s/cm^2) normal to the collector surface.
- The date is November 21.
- Latitude = 74°.
- Longitude = 41°.

A plot of minimum efficiency for different operating conditions is included in the report.

In addition to descriptions of the performance specifications, the installation, operation and maintenance procedures, and detailed drawings, the 61-page report describes methods for determining the optimum collector size. Collector sizing is an economic decision as well as a technical one. In contrast to conventional heating or air-conditioning systems that are sized to handle peak loads (since they do not generally operate in cooperation with backup systems), the solar system is sized to handle only a portion of the peak-load demand. The balance of the load is absorbed by a backup system.

The sizing calculation is thus carried out in two steps: (1) The total energy requirements for domestic hot water and space heating are ascertained, and (2) the collector is sized to meet a portion of these requirements. A table of the average hot-water requirements for various single-family dwellings is included in the report for use in the first calculation. In making the second part of the calculation, the collector tilt angle is determined and is used in determining the amount of insolation received per unit area of collector surface. Finally the area required to meet roughly 50 to 60 percent of the domestic hot-water requirement and 40 to 50 percent of the space-heating requirement is calculated. Comprehensive tables of collector tilt factors and average daily degree-day factors for many locations are given. [See the following article "Liquid Solar Collector — Performance Tests" (MFS-25082).]

This work was done by the Calmac Manufacturing Co. for **Marshall Space Flight Center.** *To obtain a copy of the report "Design and Installation Package for the Sunmat Flat Plate Solar Collector,"*

NASA TECH BRIEF

Marshall Space Flight Center

Solar-Energy Absorber: Active Infrared (IR) Trap

The problem:

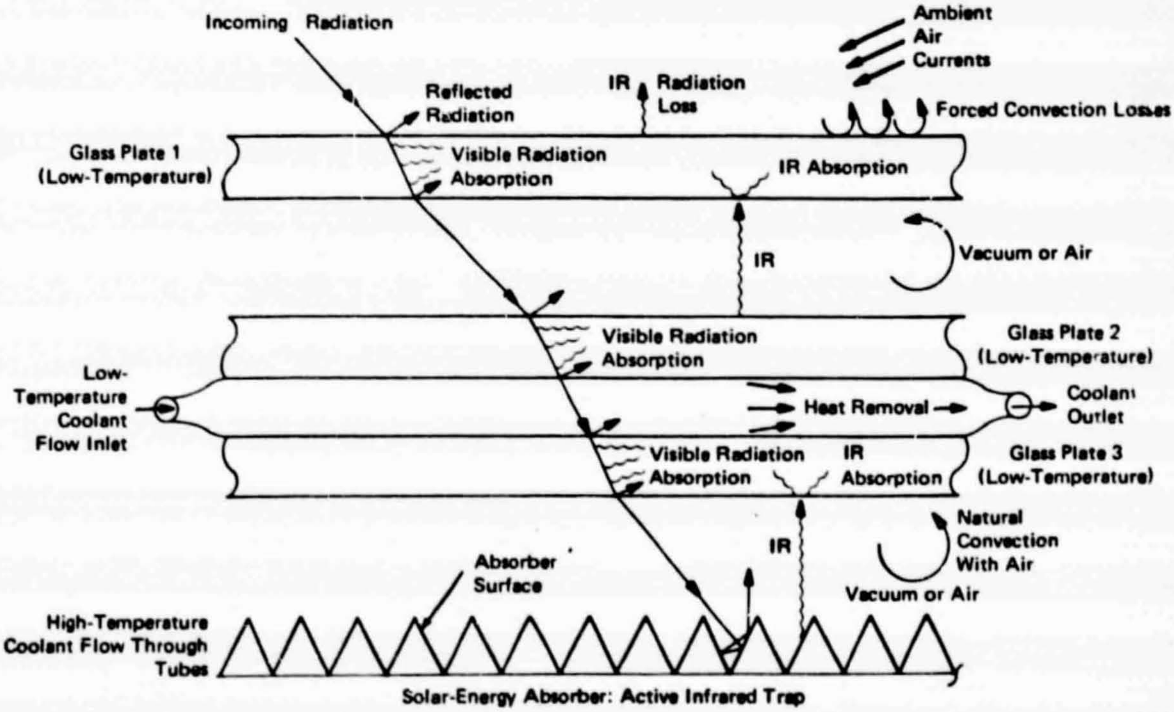
Present solar-energy absorbers, used in trapping solar radiation for thermal-to-electrical conversion systems, have efficiencies reaching 86 percent. The basic reason for the energy loss is the absorber configuration. A typical absorber collects solar heat through several glass plates located above the actual absorber surface. The transfer of heat from one plate to another depends on the temperature difference between them: the larger this difference, the more effective the heat transfer. However, as the plates absorb infrared energy, they heat up. The result is that their temperature differences minimize, thus reducing the effectiveness of heat transfer.

The solution:

The efficiency of solar-energy absorbers may be improved to 95 percent by actively cooling their intermediate glass plates.

How it's done:

In the solar-energy absorber shown in the illustration, a clear liquid or gas coolant is conveyed between two of the glass plates. The coolant removes the infrared heat trapped in the glass. As a result, the temperature difference between the plates is maximized, hence the effectiveness of heat transfer is improved. The new configuration improves absorber efficiency to 95 percent. Further improvements in absorbing efficiency may be accomplished by additional cooling between other intermediate plates.



Solar-Energy Absorber: Active Infrared Trap

(continued overleaf)

Notes:

1. The new approach may be of interest to manufacturers of solar absorbers and to engineers and scientists developing new sources of energy.
2. Requests for further information may be directed to:

   Technology Utilization Officer
   Marshall Space Flight Center
   Code A&PS-TU
   Marshall Space Flight Center, Alabama 35812
   Reference: B73-10484

Patent status:

Inquiries concerning rights for the commercial use of this invention should be addressed to:

Patent Counsel
Marshall Space Flight Center
Code A&PS-PAT
Marshall Space Flight Center, Alabama 35812

Source: L. W. Brantley, Jr.
Marshall Space Flight Center
(MFS-22743)

NASA TECH BRIEF
Marshall Space Flight Center

Selective Coating for Collecting Solar Energy on Aluminum

The problem:

Coated aluminum substrates used as collectors of solar heat require a high solar radiation absorptance and a very low thermal and infrared emittance. The efficiency of such coatings is determined by the ratio α/ϵ, where α is the absorptance and ϵ is the emittance: the larger this ratio, the higher the collector efficiency. Presently used coatings, which were originally developed for brass, copper, and steel substrates, yield relatively low α/ϵ ratios when applied to aluminum.

The solution:

A new, efficient, black-nickel plating applied to aluminum substrate enhances solar absorptance to 93 percent and reduces the emittance to 6 percent.

How it's done:

Aluminum, unlike other common metals, requires a special treatment to make it receptive to an electroplate. The entire process requires anodizing the substrate in an acid bath to produce a thin porous oxide film, plating the anodized surface with bright nickel, and finally plating the surface with black nickel.

Specifically, an aluminum surface is anodized for 10 minutes in a 350-gram phosphoric acid solution diluted in 1 liter of water. This process is carried out at a current density of 12 A/ft^2 (130 A/m^2) and a bath temperature of 80° F (26° C), using a lead cathode. The anodized substrate then is placed into a nickel bath containing the following:

Nickel sulfate ($NiSO_4 \cdot 6H_2O$)	10 oz/gal (70 g/1)
Nickel chloride ($NiCl_2 \cdot 6H_2O$)	8 oz/gal (56 g/1)
Boric acid	5.5 oz/gal (38.5 g/1)

This solution includes special brightener and nonpitting agents constituting 7 percent of the bath volume. The plating process is carried out at a current density of 20 A/ft^2 (215 A/m^2) and a bath temperature of 120° to 140° F (48° to 59° C) for approximately 30 minutes, the time necessary to produce a nickel coating thickness of approximately 0.5 mil (0.01 mm).

The plated surface then is buffed, cleaned in an alkaline solution, dipped into a 30-percent hydrochloric acid solution, rinsed, and introduced into another nickel bath. The second bath composition contains the following:

Nickel sulfate ($NiSO_4 \cdot 6H_2O$)	10 oz/gal (70 g/1)
Nickel ammonium sulfate [$NiSO_4(NH_4)_2SO_4 \cdot 6H_2O$]	6 oz/gal (42 g/1)
Zinc sulfate ($ZnSO_4 \cdot 7H_2O$)	5 oz/gal (35 g/1)
Sodium thiocyanate (NaCNS)	2 oz/gal (14 g/1)

Plating is continued for the period of time necessary to produce a surface with a solar absorptance of 0.9 and a thermal or infrared emittance of 0.06. This time is determined empirically. In general, 5 minutes of plating time at a current density of 0.5 A/ft^2 (5.4 A/m^2) are sufficient to produce these optical qualities.

Notes:

1. This process may be of interest to engineers and scientists investigating new sources of energy.
2. Requests for further information may be directed to:

   Technology Utilization Officer
   Marshall Space Flight Center
   Code A&PS-TU
   Marshall Space Flight Center, Alabama 35812
   Reference: B73-10527

Patent status:

Inquiries concerning rights for the commercial use of this invention should be addressed to:

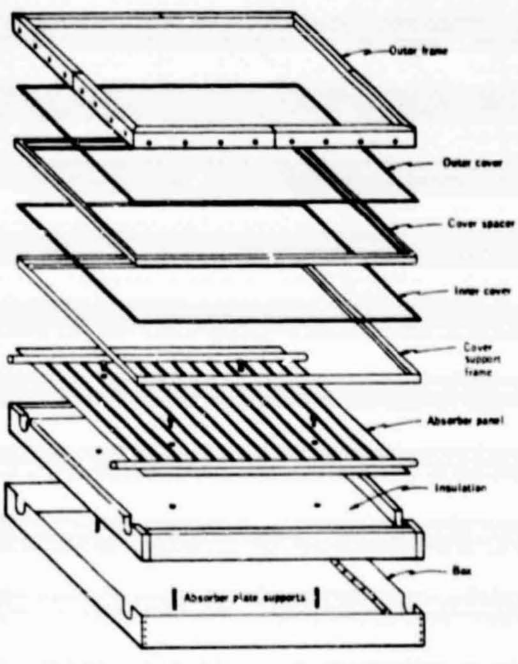
Patent Counsel
Marshall Space Flight Center
Code A&PS-PAT
Marshall Space Flight Center, Alabama 35812

Source: J. R. Lowery
Marshall Space Flight Center
(MFS-22562)

Category 03, 04, 08

NASA TECH BRIEF
Lewis Research Center

Comparative Performance of Twenty-Three Types of Flat Plate Solar Energy Collectors



SOLAR ENERGY COLLECTOR ASSEMBLY

To aid in the development of alternate energy sources, NASA's Lewis Research Center is exploring the use of solar energy for heating and cooling buildings. An important part of this effort is investigating the potential of flat plate solar energy collectors to convert solar energy into heat. Flat plate solar energy collectors are essentially black-colored metal panels which absorb heat from the sun and transmit the absorbed heat to a working fluid. A transparent glass or plastic cover encloses a dead-air space or a vacuum to limit re-radiation from the panel (see figure).

Various designs of flat plate collector have been tested and evaluated under simulated (indoor) and actual (outdoor) conditions. The performances of twenty-three types of collector tested under simulated conditions have been published in a recent report (Note 1). From the test data, efficiencies of these collectors have been determined for four different purposes: operating a Rankine-cycle engine (working fluid at 388 K (240°F)); heating (322 K (120°F)) or absorption air-conditioning (366 K (200°F)); heating hot water (333 K (140°F)); and heating a swimming pool (300 K (80°F)). The efficiencies were also determined for a noon-hour and an all-day basis for the above four conditions.

The twenty-three types of collector tested included various combinations of copper, aluminum and steel panels, coated with flat black paint, copper oxide, black chrome, black nickel or chemically etched and all covered with glass, plastic or anti-reflection glass covers. Some collectors contained a plastic honeycomb placed between the panel and cover to channel the sunlight and reduce heat loss.

The results showed a wide range of performance efficiencies for the purposes for which the collectors were tested. The NASA/Honeywell collector (#22) had the highest efficiency of any collector tested for the purposes of a Rankine-cycle engine, heating or absorption air-conditioning a building and heating hot water. The NASA/Honeywell collector (#22) was designed using two anti-reflection glasses and black nickel as a solar selective coating. Another NASA/Honeywell designed collector (#8) had the highest efficiency for the purpose of heating swimming pools. Collector #8 was designed using black paint as a coating and a single glass as a cover.

The tests were performed in an indoor solar simulator facility which closely simulates the average North American sunlight and enables tests to be conducted under controlled and repeatable conditions. The simulator was designed and built by the NASA Lewis Research Center.

Notes:

1. Further information is available in the following report:

   NASA TM-X-71793 (N75-32591), Flat-Plate Solar Collector Performance Evaluation with a Solar Simulator as a Basis for Collector Selection and Performance Prediction

(continued overleaf)

Copies may be obtained at cost from:

Technology Application Center
University of New Mexico
Albuquerque, New Mexico 87131
Telephone: 505-277-3622
Reference: B75-10189

2. Specific technical questions may be directed to:

Technology Utilization Officer
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Reference: B75-10189

3. The solar simulator used in these tests was announced previously in NASA Tech Brief 74-10086. Further details have been published in the following report:

NASA TM-X-3059 (N74-27719), Low-Cost, Air Mass 2 Solar Simulator

Copies may also be obtained from the Technology Application Center (address above).

Patent Status:

NASA has decided not to apply for a patent.

Source: F.F. Simon
Lewis Research Center
(LEW-12511)

N77-31611*# National Aeronautics and Space Administration Marshall Space Flight Center, Huntsville, Ala.

STAINLESS STEEL PANEL FOR SELECTIVE ABSORPTION OF SOLAR ENERGY AND THE METHOD OF PRODUCING SAID PANEL Patent Application

Marion L. Roberts, Max H. Sharpe, and Albert C. Krupnick, inventors (to NASA) Filed 2 Sep. 1977 17 p

(NASA-Case-MFS-23518-2; US-Patent-Appl-SN-830382) Avail: NTIS HC A02/MF A01 CSCL 10A

A panel for selectively absorbing solar energy comprises a stainless steel metal substrate coated by a natural oxide of the metal. The panel is made by heating a cleaned stainless steel substrate in an oxygen-containing gas at 1500 - 1700 F. NASA

N78-19599* National Aeronautics and Space Administration Lewis Research Center, Cleveland, Ohio.

SELECTIVE COATING FOR SOLAR PANELS Patent

Glen E. McDonald, inventor (to NASA) Issued 25 Oct. 1977 6 p Filed 22 Dec. 1975 Supersedes N76-15603 (14 - 06, p 0741)

(NASA-Case-LEW-12159-1; US-Patent-4,055,707; US-Patent-Appl-SN-643041; US-Patent-Class-428-652; US-Patent-Class-126-270; US-Patent-Class-427-160; US-Patent-Class-428-667; US-Patent-Class-428-679) Avail: US Patent Office CSCL 10A

The energy absorbing properties of solar heating panels are improved by depositing a black chrome coating of controlled thickness on a specially prepared surface of a metal substrate. The surface is prepared by depositing a dull nickel on the substrate, and the black chrome is plated on this low emittance surface to a thickness between 0.5 micron and 2.5 microns.

Official Gazette of the U.S. Patent Office

High-Performance Flat-Plate Solar Collector

Absorber material, selective coating, and collector design are combined to improve efficiency.

Caltech/JPL, Pasadena, California

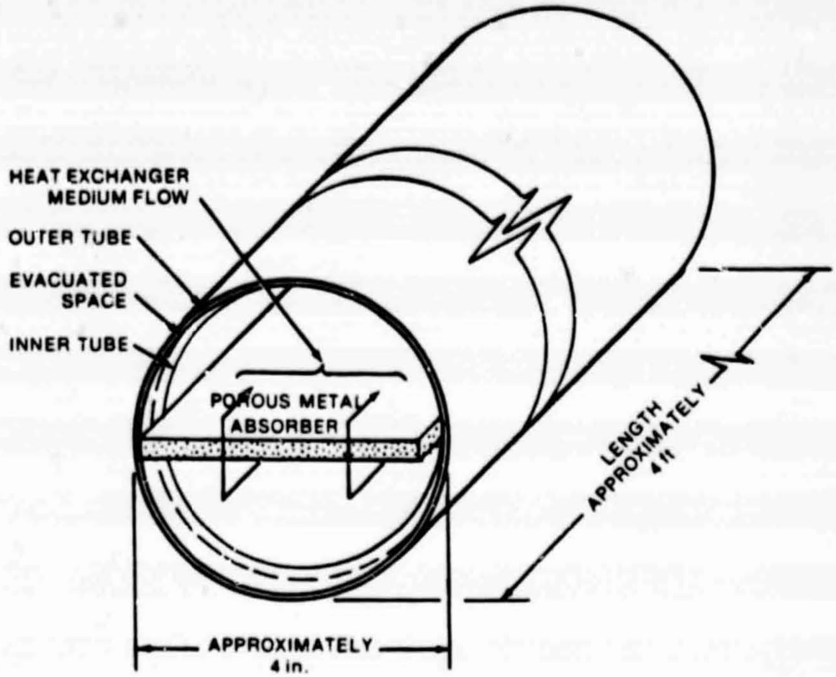
By refining and combining several known techniques, a proposed solar collector could be more efficient and could operate at a higher temperature than previous collectors. The collector, as shown in the illustration, would comprise three basic approaches:

- a vacuum to reduce convection losses,
- a selective coating, and
- a porous absorber.

All three concepts are implemented and combined with improvements that should increase the cost effectiveness of the system.

The collector is an evacuated, concentric tubular envelope surrounding a flat-plate absorber. The evacuated envelope is used to reduce heat losses from convection and conduction. In contrast to existing systems that used the inner tube as a heat exchanger, the use of the flat plate is expected to enhance the absorber-to-gas heat exchange.

The other primary source of heat loss in solar collectors is the reradiation of absorbed energy. Like many other systems, a thin selective coating would be used to achieve high absorbance of solar radiation and low emittance of the reradiated longer wavelength radiation. However, one of the problems with selective coatings is that their effectiveness increases rapidly as the angle of incident solar energy approaches the plane of the collector. This increases the long-wavelength emittance of the system and reduces the efficiency of the system. The coating emittance and angular dependence can be lowered by making it thinner, but this also reduces the amount of absorbance.



The Concentric Glass-Tube-Envelope Collector surrounds a flat-plate absorber having a spectrally selective coating. The envelope is transparent with an antireflection coating. The heat-transfer medium is a gas, such as air, that circulates along a hairpin path as shown by the arrows.

These contradicting requirements could be resolved by using a porous metal as the substrate on which the coating is deposited. The porosity increases the absorption surface area and increases the absorbance of the copper by "trapping" radiation in the pores (multiple internal reflections). On the other hand, copper emittance will not increase much, as it occurs mostly on the outermost sufaces of the plate and will not be appreciably enhanced by the pores.

This increased absorption allows effective use of a selective coating. For instance, a thin dielectric coating that absorbs (appears black to) wavelengths shorter than 3 μm could be placed over porous copper. This same coating can be selected to be transparent to the longer infrared wavelengths emitted by the copper. Thus, the coating will absorb solar radiation; but because of the transparency region of the coating, the emittance will be that of the longer wavelength source, the copper. The emittance of polished copper is about 0.04 at solar-collector temperatures, and the absorbance of typical coatings is

(continued on next page)

around 0.9. Thus, the absorbance-to-emittance ratio can be made quite high.

However, the real advantage of the porous copper accrues when the coating is made very thin to insure that the collector emittance is that of the copper and is not increased by the coating thickness. Polished copper has an absorbance of only 0.35; and when combined with a thin coating with a much-reduced absorptance, the total absorbance-to-emittance ratio drops significantly. With the porous substrate, a thin dielectric coating can be used while retaining significant absorbance.

This work was done by Rollin K. Reynolds of Kentron-Hawaii, Ltd., for **Caltech/JPL** *and Glen McDonald of* **Lewis Research Center.**

Selection Standard for FEP Films for Solar Energy

"Purple" FEP films are more efficient due to low absorptance.

Lyndon B. Johnson Space Center, Houston, Texas

For highest efficiency, Teflon films used as thermal-control coatings in solar-energy conversion systems should have low absorptance in the solar spectrum. Because the levels of various brown/purple tints in a typical production batch are unpredictable, however, absorptance values in Teflon can vary by 30 percent or more. In a recent measurement on fluorocarbon ethylene propylene (FEP) Teflon films obtained for the Space Shuttle program, for example, the solar absorptance values varied between 0.062 and 0.095.

Designers seeking to improve the coatings were able to quantify this effect and to devise a simple screening test based on the transmittance of the films. Samples that passed the test had absorptances as low as 0.059, or lower than the best coatings previously obtained.

The transmittance of films with brown tints was found to be lower than that of the more purple films, with the effect being most pronounced at shorter wavelengths (i.e., in the ultraviolet). Thus, the transmittance at 0.33 micron was chosen as the test wavelength, and the film-selection criterion was set at a transmission of at least 83 percent (that measured for the clearer purple samples). Brown films, in comparison, gave typical transmittances around 69 percent.

By selecting only the purple films with transmittances exceeding 83 percent at 0.33 micron, coatings with more uniform and lower absorptance values were consistently obtained.

This work was done by Madison W. Reed of Vought Corp. for **Johnson Space Center.** *No further documentation is available.*
MSC-16999