CATCH THE SUN

Although solar energy is available today, many researchers believe the best is yet to come

BY JANET RALOFF

Solar energy-conversion systems are often referred to as new or "advanced," and discussed in terms of their future contributions. But such references downplay solar's past. In the introduction to his book, Solar Energy, Bruce Anderson quotes from Xenophon's Memorabilia on Socrates' (470-399 B.C.) teachings about "passive" solar design. The Greek mathematician Archimedes (about 287 B.C.) is alleged to have defended his native city, Syracuse, by setting afire the sails of approaching Roman ships with sunlight focused off a battery of convex mirrors. For high-temperature experiments, Lavoisier used a solar furnace that could attain temperatures to 2,000° F. And the oxygen that Priestley discovered was produced by heating metal oxides with a "burning lens." Auguste Mouchot made a solar-powered steam engine, later used to pump water in Algeria, during the late 1860s. And the solar still built at Las Salinas, Chile, in 1871 to desalinate 6,000 gallons of water a day, operated for 40 years.

Perhaps the earliest existing sign of American solar design is "Montezuma's Castle," a seven-story masonry structure built into a rocky New Mexico bluff. John Yellott, a consulting solar engineer, calls it an excellent example of passive design — one requiring no external mechanical power to move heat. Tree-ring dating of beams from the "castle" floor indicate it was under construction from A.D. 730 to 1330. Its natural overhang shields it from direct rays of the harsh summer sun, but in winter the sun streams in.

Active solar systems — those requiring mechanical power — were also widely used in sunny climates, though not so early. In the fall 1977 COEVOLUTION QUARTERLY, Ken Butti and John Perlin write that by 1897, 30 percent of all Pasadena, Calif., homes used solar-heated hot water. And by 1940 there were approximately 60,000 solar water heaters in the Miami area alone, according to C. R. Johnson of the Florida Solar Energy Center (FSEC). Where did they go? Huge finds of oil and natural gas eroded the economics of solar heating, Butti and Perlin write. And gas heaters with automatic temperature control soon appeared to make heating water easier and more dependable. An FSEC report adds that maintenance problems in aging systems, such as corrosion, pipe leaks and collector damage from freezing weather, further dampened solar's image.

Today Americans are rediscovering solar energy. After 13 editions, William Shurcliff (see p. 269) abandoned his survey of solar-heated buildings last year because he could no longer keep pace with builders. Even gas and electric utilities are looking into "going solar" or into encouraging customers to do so. A solar comeback? All indications are that this one won't be temporary.

Harness the sun? That's something the ancients thought only gods could do. But over the years science and technology have been developed to the point where we can now transform what were once dreams into hardware systems that convert diffuse sunshine into useful and powerful energy. Dwindling fuel reserves have put an added premium on that transformation, so the Department of Energy (DOE) is investing more than $400 million a year in solar research (and it appears that several tens of millions more will be added to next year's solar budget in the form of supplemental funds, the details of which are only now being worked out). What follows is a glimpse of the diversity and ingenuity being exerted to harness the sun.

PHOTOVOLTAICS . . .

A flurry of activity excites the search for low-cost photovoltaics — solar cells that convert sunlight into electricity. Silicon solar cells, famous for powering spacecraft far from home, would be used to power more on earth if they didn't cost so much. Now selling for upwards of $10 or $12 per peak watt (what the output would be under the best possible conditions — noon on a sunny day), they aren't expected to be competitive with terrestrial-generated electricity until their cost drops to $.50 per peak watt. (There are exceptions, however; slapping a few solar cells on a buoy at sea or remote military installation in the Arctic costs far less than installing power lines from the nearest utility.)

Reducing silicon-cell costs by a factor of 10 or more won't come easily or cheaply, and a number of competing technologies are boasting they'll reach a magic $1 or $.50 per peak watt long before silicon. The energy-conversion efficiency for most of these competitors falls well below that of silicon — now averaging roughly 12 to 14 percent—but most are confident they can at least come close to matching it within a few years. Thin film technology is what makes much of this competition possible. Depositing thin layers of semiconductor materials—by painting, spraying, sputtering or some other means — eliminates some of the most costly steps in production of conventional solar cells, that of pulling pure-silicon crystals, cutting them into thin wafers and preparing wafer surfaces.

Thin-film polycrystalline solar cells made from cadmium sulfide (CdS) and copper sulfide (Cu_2S) made their debut more than 20 years ago. For much of that time they posed little threat to silicon-cell supremacy because their energy-conversion efficiency was so low. But now that's changing. John D. Meakin of the University of Delaware says cells developed at the university's Institute of Energy Conversion are finally sporting efficiencies "a hair over 8.5 percent.... Our goal is 10 percent by the end of this year." And it's entirely reasonable that CdS-Cu_2S cells may be available for $.20 to $.30 a peak watt within 10 or 15 years, he said. At those prices "photovoltaic electricity may be competitive with electricity sold at bulk rates to large industrial consumers," says Henry Kelly of the Office of Technology Assessment in the Feb. 10 SCIENCE.

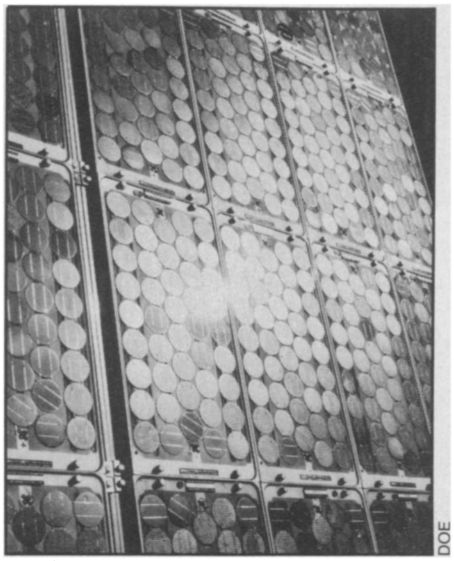
What's more, the Institute of Energy Conversion is finishing a design of a pilot plant that it expects will prove that CdS-Cu_2S cells can be made and *sold* for $2 per peak watt by 1981 or 1982, according to the institute's director, Allen M. Barnett. A follow-up program is expected to demonstrate production of solar cells that can be sold for $.25 per peak watt by 1987 or 1988, he told SCIENCE NEWS.

Harold J. Hovel of IBM's research center in Yorktown Heights, N.Y., says gallium arsenide (GaAs) solar cells are "a dark horse candidate," but still very much in the race. Also produced using thin-film technology, their manufacture should cost less than single-crystal silicon. Materials costs are not so easy to reckon, however, because you can't buy gallium. It is most commonly seen as an impurity in aluminum. Designers are told that if demand for gallium arises, it will be marketed; but no one knows at what price.

The principal advantage of GaAs cells is their efficiency. Last year, Hovel and co-worker Jerry Woodall reported on cells with an energy-conversion efficiency of 21.9 percent. Thermal output of the cells is also high, something most designers are only now coming to appreciate. "GaAs is capable of converting sunlight into electricity at 20 percent efficiency while delivering hot water or steam at 100°C to 200°C," Hovel says, "making use of nearly all incoming solar energy."

A normal photovoltaic cell typically converts 20 percent of the energy it receives into electricity and 70 percent into heat; the remainder generally is lost due to reflection. Until recently, a solar cell's thermal output was thrown away, Hovel said, although it's "just ideal" for residential applications. While cells generate electricity to run appliances they can be replenishing a store of hot water or warming a house. In fact, the University of Delaware's experimental house, Solar One, built in 1973, is using solar cells to demonstrate just such dual-purpose applications, Meakin says.

Discovery of amorphous semiconductors, less than a decade ago, broadened the lineup of photovoltaic contenders. Solar cells made from thin films of amorphous silicon have achieved efficiencies of six percent. David Carlson heads the program that produced these cells at RCA's Princeton, N.J., research center. The term amorphous spells out the important structural difference between these and conventional solar cells. Silicon used in ordinary cells is a crystal — pure and orderly —also expensive to produce. The molecular structure of amorphous silicon is less orderly. It's also less expensive and far simpler to make. Carlson says he expects to see commercial introduction of such cells within five years at a cost of about $1 per peak watt. At that cost they're already competitive with the higher efficiency regular silicon cells, he says, but "if we can get [efficiencies of] 10 percent or more, I don't see how anybody could touch us," he told SCIENCE NEWS.


DOE
Solar cells: Sunlight to electricity.

Chalcogenide glasses are among the many amorphous materials being investigated for production of commercial solar cells at Energy Conversion Devices in Troy, Mich. Stanford Ovshinsky is ECD's president and a man who more than once has been described as having miraculously achieved things in electronics that everyone else "knew" couldn't be done. Describing his solar-cell program as "ambitious," Ovshinsky said, "We feel we have solved the problems that have held down the efficiencies" of other solar cells.

ECD is already making and testing solar cells, Ovshinsky says, but details of the program remain a mystery because he has not reported on their energy-conversion efficiencies to the scientific community. He did tell SCIENCE NEWS that "we contemplate achieving efficiences around 10 percent in the coming year," and that commercial introduction of his amorphous cells may also occur within the next year or so. At what cost? Ovshinsky says, "We feel we'll be competitive" with the average cost of electricity generated by more traditional sources, such as coal or nuclear power, once cells are mass produced in large volumes.

Ordinary solar cells have a single semiconductor junction, but "cascading" systems with two or more junctions are in the works. Research Triangle Institute in North Carolina, for instance, is beginning design of "monolithic cascade solar cells" with predicted energy-conversion efficiencies of more than 30 percent. RTI's Robert Burger says single-junction solar cells operate best at only one wavelength of light. In cascading, each junction is engineered to use a different part of the solar spectrum. By tailoring this structure so that layers become additive, you increase the collection efficiency of the entire cell, Burger says.

Each semiconductor layer must be transparent to wavelengths that it does not use so that spectral regions unused by one layer will be accessible to others. Layers are grown epitaxially. (Epitaxy is a process in which different materials are grown on a base of crystal.) The cells will be more expensive than ordinary solar cells, but when used with solar concentrators, the cost of a cell becomes only a fraction of the system cost, Burger says. Prototype cells, probably using intermetallic alloys such as gallium-indium arsenide, should be completed within a year, he says.

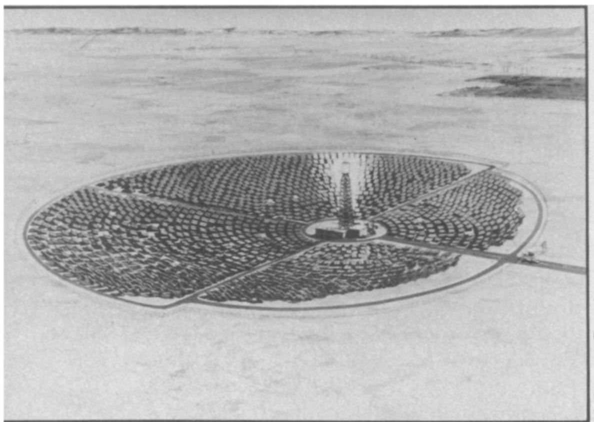
A manufacturing technique that could increase the conversion efficiency of all types of solar cells — single crystal, polycrystal and amorphous — is being tested at Colorado State University. Called neutralized ion-beam sputtering, it is a way to implant semiconductor layers of indium-tin oxide onto cells. Cells so produced usually exhibit greater electrical conductivity, and bonded layers are so thin that optical transparency increases (meaning it's easier for wavelengths unused by upper layers to proceed to lower ones), according to CSU's Alan Genis. Polycrystalline cells produced in this way have shown the highest efficiencies to date, Genis told SCIENCE NEWS, and RCA's Carlson said he just sent CSU some of his cells to be tested.

The procedure is simple, operates at low temperatures and produces less cell-surface damage than comparable techniques, Genis says. Cost of the neutralized (noncharged) argon-beam used in the "sputtering" could double the capital cost of production equipment, but resulting improvements in efficiency and conductivity may be worth it, Genis says.

Another variation on the photovoltaic theme is the liquid-junction solar cell under development at Bell Telephone Laboratories by Adam Heller, Barry Miller and Murray Robbins (SN: 6/25/77, p. 410). The cell consists of two electrodes, GaAs and carbon, immersed in an aqueous solution such as selenide-polyselenide. Its notable advantages are simplicity and nine-percent efficiency.

...THE POWER TOWER

The biggest solar-electric project in this country has little to do with photovoltaics. At a site near Barstow, Calif., 1,760 identical and slightly curved mirrors arranged in 32 circular arcs will track the sun daily, focusing sunlight onto a central solar-energy absorber located more than 250 feet above ground. Cold water pumped up the tower will return as 960°F superheated steam to generate power. This 10-megawatt solar-power tower is being developed for DOE by McDonnell Douglas Astronautics Co. and the Rocketdyne Division of Rockwell International.



McDonnell Douglas

A 72-acre field of mirrors to boil water.

The familiar flat-plate collector seen atop many homes since the late 1800s is also undergoing change. Traditionally, a blackened metal plate—usually copper or aluminum—has been used to absorb sunlight; heat is carried away by air or fluids circulating in pipes through the collector. Collectors are black because only perfectly black surfaces absorb all wavelengths of light. Black paint and other common coatings are not a perfect black, however, and if they are shiny, dirty or faded they will collect even less. Wendell Williams of the National Science Foundation believes collector surfaces can be engineered better to increase the spectral band, and therefore the energy, they absorb. Hafnium carbide, one of a class of transition-metal carbides, looks promising, he says, but has yet to be tested. It's strong, stable at high temperatures, can be applied in thin films and endures repeated hot-and-cold cycling, he says.

...EVACUATED TUBES

Even the tubes that route heat-exchange fluids through solar collectors are changing. General Electric Co. and Owens-Illinois, Inc., are among developers of evacuated tubes. GE's version resembles tubular fluorescent lights. Each is really a glass cylinder within a cylinder, with a small vacuum space separating inner and outer tubes. The vacuum insulates the inner heat-absorbing tube, much like a thermos bottle, to minimize heat loss. Energy is absorbed by this tube's spectrally selective surface and conducted into the heat-transfer medium via thin metal fins on the tube's inner surface. Surrounding tubes with reflectors increases their collection-gathering ability. GE claims that collectors using its tubes and reflectors can supply nearly double the energy of conventional flat plates, as 250°F water.

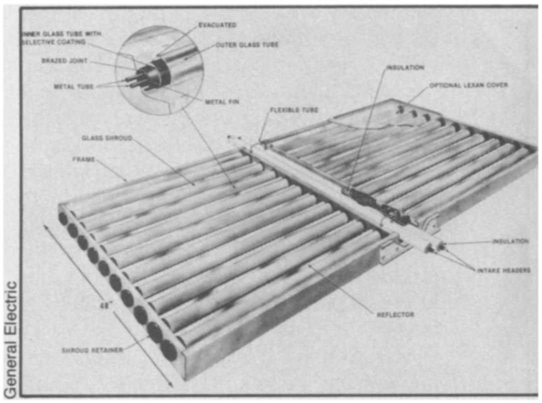
Another variation of the flat-plate collector circulates a "black" (actually blue, green or brown may work equally well) fluid through a transparent collector. Finding stable fluids that do not fade, clog passages or degrade piping has been a problem. One fluid that performed well in almost 6,000 hours of tests by the Boeing Co. in Seattle contained carbon particles dispersed in ethylene glycol (antifreeze) and water. It was available in 1975 for $.08 per gallon.

Boeing designed its glass collector so that it could be manufactured "quite inexpensively" using an automated glass-forming process that would roll and fuse three glass sheets into a collector sandwich. Top and bottom sheets are flat, the middle is corrugated into vacuum (insulation) panels and working-fluid passages.

Czeslaw Deminet, one of the Boeing designers, says the collector is ideal for heating greenhouses in the Southwest where the "terrarium syndrome" clouds their utility. Greenhouses are such efficient solar collectors that they can overheat and kill crops. Deminet says evaporative cooling, using brackish or salt water, has been a solution, but it requires additional energy to power forced-air circulation. And "care must be taken with certain crops to avoid transport of salt-laden aerosols," he says.

For greenhouse applications, the Boeing collector would use a working fluid with spectral qualities that permit passage through the collector of light wavelengths used by plants for photosynthesis. "Undesirable" radiation would be collected for night heating or for desalinization of salt water for crop irrigation, Deminet says.

A plastic, residential version of the same concept is under design at the Battelle Memorial Institute's Columbus laboratory. D. Karl Landstrom, who heads the program, says the low-temperature, low-cost collector is expected to significantly outperform comparable black-absorber flat-plate collectors.



General Electric

Evacuated tubes work like thermos bottle.

...SOLAR PONDS

Tests on another low-temperature, low-cost concept for agricultural or rural heating are being conducted by Ted H. Short and colleagues at the Ohio Agricultural Research and Development Center in Wooster. Their solar pond is a spin-off of Carl Nielson's work at Ohio State University. About 10 feet deep, 60 feet long and 28 feet wide, the pond collects heat all summer, building to a thermal high of about 180°F in fall. During winter, heat is extracted from the bottom.

Warm water, less dense than cool water, tends to rise to the surface where it will lose heat to the atmosphere. To keep his solar pond from doing the same, Short adds salt. Salt content varies with depth: 15 percent by weight at the bottom, 7.5 percent halfway up, fresh water on top. There's no circulation, so the dense water at the bottom stays put "like a glob of jello," Short says. Heat is lost only via conduction, and styrofoam insulation along the sides and floor tend to keep that at a minimum. The pond is open on top; covers only tend to reduce the solar input, Short says. Even though 6 to 10 inches of ice or snow may accumulate on its surface, the pond maintains 100°F water at its bottom through winter, Short says.

Ted Taylor, former government atomic-weapons expert is designing a community solar pond at Princeton University to heat, cool and generate electricity for a 100-house faculty complex. Oil costs more than $2 per million Btu, Taylor says. This system may (and will try) to provide heat at costs competitive with oil. In addition, it will provide summer cooling (something these old houses had not had before) from ice built up gradually all winter, and on-site generated electricity. There is even reason to believe the electricity can be generated at costs competitive with what the utilities offer.

The key to making solar energy competitive "is not to think too small," Taylor told scientists at an energy conference last fall. "A great deal of the worldwide effort is going into single houses. I see no point whatever in demonstrating that you can heat a house with a $50,000 heating system. We know that. Yet that's part of the

DOE program. What we don't know, what we haven't demonstrated, is how to solar heat houses at costs that are reasonable and [able to] take the full energy load."

More than 1,000 miles away in Grants, N.M., Standard Oil of Ohio and DOE are developing low-cost shallow solar ponds as a source of process (commercial and industrial) heat. Unlike Short's deep pools, Sohio's ponds resemble huge waterbeds; each is 3.5 meters wide, 60 m long and contains water 5 to 10 cm deep. The top is transparent, the bottom an energy-absorbing black. A bed of insulation below prevents heat loss to the soil and a corrugated-fiberglass panel arched atop the pond suppresses convective and radiative heat losses. The total installed cost of such a collector (including site preparation) is about $5 to $10 per square foot, says William C. Dickinson, who heads the solar program at Lawrence Livermore Laboratory and who coordinated this project. "It's already competitive with systems burning oil at $17 per barrel," he says.

Three ponds were tested last year. As a result of their performance, we'll be seeing more — in an Alabama chicken-meat processing plant this year and at Fort Benning, Ga., next year.

... RADIATION FUNNEL

Another contender for delivering low-cost process heat is the compound parabolic concentrator (CPC) under test at Argonne National Laboratory. Walls of the CPC's mirrored troughs are formed from the inner sides of two intersecting parabolas. The CPC acts like a radiation funnel collecting all light falling on the collector aperture, says Argonne's Ari Rabl. It is non-focusing and non-imaging, and it offers the highest possible concentration for a given acceptance angle, he says. In fact, the sun can traverse a 40-degree arc without leaving the absorber's field of view. The absorber may be nothing more than a black tube filled with a heat-exchange fluid, running the length of the collector trough. But CPC's designs for higher temperatures deliver better efficiencies using evacuated-tubes as their absorbers.

Unlike other parabolic concentrators, the CPC concentrates a significant fraction of diffuse (hazy day) in addition to direct sunlight. For low power concentrations, it doesn't need to track the sun (something that requires elaborate and expensive equipment). When tracking is necessary, it's done far less often than for concentrators with comparable magnifications. The CPC reflector is "very inexpensive," Rabl says, about $2 per square foot for aluminum versions and as low as $.50 per square foot for plastic.

... SYNTHETIC LEAVES

Some of the more intriguing solar concepts are a long way from commercial trials. Argonne's "synthetic leaf" is one example. Joseph Katz, Thomas Janson and M.R. Wasielewski have developed a device to mimic the light-mediated electron transfer performed by photoactive chlorophyll in green plants. Some chlorophyll species eject electrons when illuminated with red light. The scientists are studying how this occurs with the long-range goal of engineering a "plant"—either of biological material, such as harvested chlorophyll, or of electronic parts — that can generate electricity or break down water into hydrogen and oxygen. In the engineering they may even be able to improve on nature, making their plant receptive to more of the solar spectrum so that less energy is wasted.

Another sort of synthetic leaf is being developed by Norman Sutin and colleagues at Brookhaven National Laboratory. Metal complexes similar to chlorophyll in some of their properties absorb light photons. Absorbed photons bump electrons from the outer shell of metal atoms and into higher energy levels. If an "excited" electron is not captured in a chemical reaction within 10^{-6} or 10^{-12} seconds, it returns to its lower energy level, ejecting the extra energy as heat and light.

Sutin says ruthenium trisbipyridine ions make good candidates for the metal complex. Their light-absorbing properties are good and their excited-state lifetime is long enough so that they can be harnessed as a reducing agent to produce hydrogen gas from water. The concept solves one problem inherent in most solar-collection systems — how to store solar energy for when the sun doesn't shine. Hydrogen stores well and is an efficient fuel.

A University of Georgia team is working on photochemical storage using norbornadeine (NBD) and its high-energy isomer quadricyclene (Q). NBD is transparent, so it won't absorb sunlight, says UG's C. Kutal. A chemical intermediary must be used to absorb the light and transfer its energy to NBD. Once that occurs, NBD converts to the isomer, storing 230 "small" calories of solar energy per gram of Q. Since Q is inert, Kutal says, the energy can be stored indefinitely. To liberate it, one adds a chemical catalyst — back comes NBD, good as new.

What might an operating system look like? Kutal speculates that rooftop solar collectors might be lined with the light sensitizer and the inner surface of room radiators might be coated with the Q catalyst. To store energy one would run the NBD through the collector; to warm a room, merely circulate Q through the radiator.

Harry B. Gray at the California Institute of Technology is working on yet another photochemical system. A rhodium compound discovered by Gray and Caltech colleagues last year produces hydrogen upon exposure to visible light. Pairs of electrons are needed to create chemical bonds, such as occur in the production of hydrogen gas, Gray says, but few photoactive chemicals liberate more than one electron at a time. The rhodium compound does. Because the reaction is reversible, hydrogen must be removed shortly after it forms.

Right now the efficiency of the system is quite low, but the chemists plan to "fine tune" their molecule, replacing various atoms and altering the compound's molecular structure to lower its cost and to upgrade its efficiency. Mark Wrighton at the Massachusetts Institute of Technology has developed a system to generate oxygen from water and sunlight. The two groups are collaborating with hopes of engineering an efficient "total" system for solar-activated electrolysis.

... HYBRID COOLER

Most solar systems are designed to warm man's environment, but the sun can cool too. There are a variety of systems under design, but one hybrid approaching commercialization is the Institute of Gas Technology's Solar-MEC. Not only does it cool, it heats, humidifies, dehumidifies and ventilates. For cooling, room air passes through a drying wheel containing a desiccant called a molecular sieve (a form of sodium aluminum silicate chosen for its ability to retain water even at high temperatures). Incoming air is dried to very low moisture levels (such as 0.003 lb of water per lb of air). Dry air, cooled as it passes through a sensible-heat exchanger,

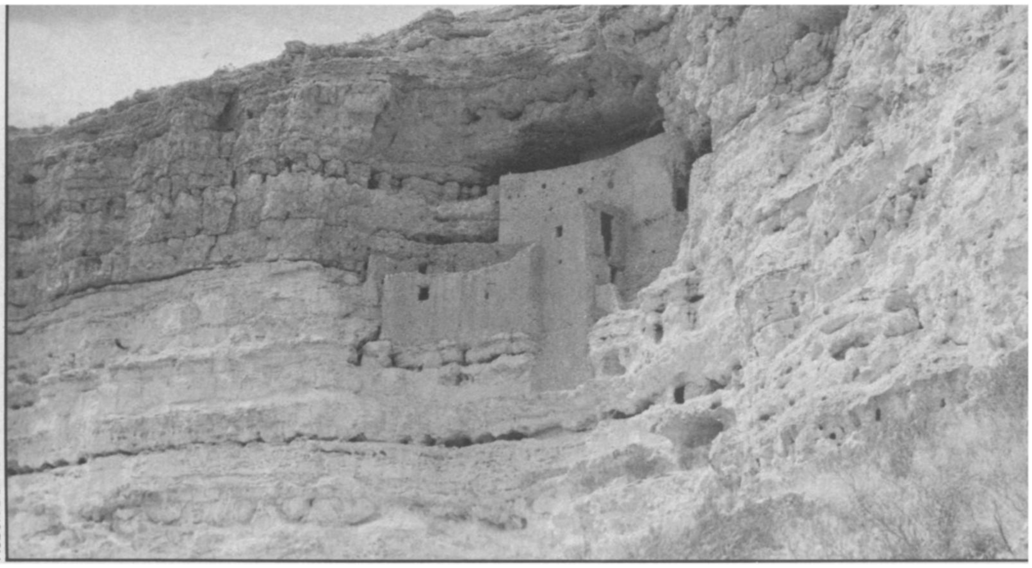
Continued on page 267

Solar homes don't have to look funny. Dark strips are collectors on Illinois home.

... Sun Catchers

is humidified and returned to the room. Running the cycle backward will heat air. This system, which has been undergoing tests for several years, has heating efficiencies comparable to those of gas furnaces, IGT says.

...AND PASSIVE



Montezuma's Castle: Precolumbian example of "passive" solar energy architecture.

Finally, no roundup of solar research is complete without a word on passive systems. Passive collectors are simple. In their pure form they contain no moving parts — a building is its own solar collector. Buildings can be designed to use every possible means of storing solar heat in walls, floors and ceiling. Although passive solar architecture is at least as old as the Pueblo Indians' adobe structures, architects and engineers are still learning why and to what extent certain materials store — and later reradiate — heat.

The newest of MIT's five experimental solar buildings is entirely passive and relies on materials developed at MIT, none of which are commercially available yet. Its polymer ceiling tiles, two feet square and one inch thick, contain a core of Glauber's salt (SN: 1/7/78, p. 8), fumed silica and other chemicals that can store a day's heat and then release it as needed. The core serves as a built-in thermostat to maintain a near constant 73 degrees. It operates on the principle of heat-of-fusion phase changes. As it radiates heat, it freezes into a solid; the next day as it takes in heat again, it melts back to a liquid. It was developed at MIT and produced by the Cab-O-Sil Division of the Cabot Corp. in Billerica, Mass. Even the venetian blinds are special. The extremely narrow louvers are mirrored in their upper surface to reflect incident solar energy onto the thermal-storage ceiling tiles. Solar energy is expected to provide 85 percent of the heat used by this building.

As with all passive buildings, designing for energy conservation is as important as designing for solar collection. A special transparent plastic sheet is inserted between the panes of double-glazed window to reflect heat that might otherwise be lost back into the room. "The window system provides better insulation than the usual wood and stud wall," and loses only 25 percent of the energy that a conventional double-glazed window would, according to MIT's Timothy Johnson.

Montezuma's Castle is the product of an early solar age — when trees (biomass) and masonry (passive solar collectors) — were among the only ways man could warm his world. Twelve centuries later, dwindling fuel supplies and environmental pollution are motivating Americans to work out how they might return to a solar age. □

... Project Sunshine

and polishing it into thin cross-sections. Three general solutions to this problem are being attempted in Japan, as elsewhere: Grow long thin crystal "ribbons," make thin films of silicon containing many smaller crystals, or use other materials that are easier to fabricate (such as amorphous semiconductors, see p. 249).

The ribbon crystal approach is being pursued by Toshiba Electric Co. and Toyo Silicon Co. The former uses a flat capillary tube to draw molten silicon out of a pool, forming a ribbon that solidifies as it is pulled vertically into the air. Toyo Silicon draws a ribbon horizontally off the surface of a pool of molten silicon, a method not yet as well developed, but one that promises faster crystal growth rates.

Hitachi Ltd. and Nippon Electric Co. (NEC) are experimenting with thin film fabrication. The former is trying to create thin layers of silicon on the surface of cheaper materials by chemical vapor deposition, vacuum evaporation and sputtering. NEC is concentrating on a method that uses a sustained plasma to aid deposition. Although thin films are much cheaper to make than silicon ribbons, their efficiency in converting sunlight to electricity is only about half as great.

Work on nonsilicon solar cells, particularly those made from compounds similar to cadmium sulfide, is being pursued by Matsushita Electric Industries. The cost of fabricating these cells is low and efficiency is higher than that obtained by silicon thin films, but the cells tend to degenerate. The cause of this degradation has now tentatively been identified and the company is trying to make a stable compound cell.

Finally, the Sharp Corp. is experimenting with ways of improving photovoltaic efficiency by improving cell design, fabrication methods and concentration of light. The company has already succeeded in making sample cells that operate with sunlight intensity increased as much as 20-fold by various focusing methods.

The upshot of this government-funded division of labor is that Japanese electronics companies have been thrust to the leading edge of research in a field that is likely to spawn a new generation of exportable products. Housetop water heaters and huge "power tower" generating systems can be made competitive only through brute-force trial and error and mass production of components. But photovoltaics will be improved by delicate experimentation, precision manufacturing and careful automation — the very areas where Japanese companies excel.

Despite the ballyhoo surrounding the launch of the Sunshine Project, relatively little money is being spent on actually trying to get Japan to switch to alternative energy sources. For fiscal 1977 only about $18 million was spent on the whole Sunshine program (of which solar energy is only one component). This compares with about $438 million spent on Japanese nuclear research. Indeed, the International Energy Agency has censured Japan for its reluctance to cooperate with other nations in non-nuclear energy development.

Perhaps the strongest indictment of the whole Japanese non-nuclear R&D effort was made by Justin Bloom, Science Counsellor at the U.S. Embassy in Tokyo, who has represented the United States in energy negotiations with Japan. He told a group of newspaper editors last year:

"On sober reflection I come to the conclusion that the Japanese people, who had heard so much about the Sunshine Project, did not truly comprehend its small scale, and were under the impression that Japan was pulling its weight in the development of solar energy, geothermal energy, coal liquifaction and gasification, etc. Today this misapprehension is fading."

If the funding for solar energy is modest, it is nevertheless strategically placed, for a half-dozen of Japan's leading high-technology companies have been launched into what is likely to become a lucrative new export market. But to see where both Japanese government and industry are placing their bets for future energy, one must look at Japan's nuclear program. That topic will be covered in a subsequent article. □