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ABSTRACT

This document is designed to give both teachers and students the opportunity to review a variety of representative articles on solar energy. Consideration is given to the sun's role in man's past, present, and future. The present state of solar technology is examined theoretically, economically, and comparatively in light of growing need for alternatives in the situation of diminishing conventional energy supplies. (Author/RE)

DOE/CS-0067

Reader

January 1979

U.S. Department of Energy
Assistant Secretary for Conservation
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SOLAR ENERGY PROJECT

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THE SOLAR ENERGY READER

THIS SECTION OF THE SOLAR ENERGY CURRICULUM MATERIAL HAS BEEN DESIGNED TO GIVE BOTH TEACHERS AND STUDENTS THE OPPORTUNITY TO REVIEW A VARIETY OF REPRESENTATIVE ARTICLES ON SOLAR ENERGY. CONSIDERATION IS GIVEN TO THE SUN'S ROLE IN MAN'S PAST, PRESENT, AND FUTURE - FROM THE ANCIENT WORSHIP OF "HELIOS" TO THE PRODUCTION OF ELECTRICITY BY PHOTOVOLTAIC CONVERSION. THE PRESENT STATE OF SOLAR TECHNOLOGY IS EXAMINED THEORETICALLY, ECONOMICALLY, AND COMPARATIVELY IN LIGHT OF THE GROWING NEED FOR ALTERNATIVES IN A WORLD OF DIMINISHING ENERGY SUPPLIES.

THE FUTURE OF THE SUN AS A RELIABLE ENERGY SOURCE IS LARGELY DEPENDENT UPON ITS ACCEPTANCE AS A VIABLE ALTERNATIVE BUT FIRST, IT MUST BE UNDERSTOOD, AND MANY PROBLEMS - ECONOMIC, SOCIAL, AND LEGAL - MUST BE SOLVED. HERE WE ATTEMPT TO EXHIBIT BOTH THE SIMPLICITY AND THE COMPLEXITY OF A SOURCE OF ENERGY AS INEXHAUSTIBLE AND BOUNTIFUL AS TIME.

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ACKNOWLEDGEMENTS & ABSTRACTS

The Solar Energy Education Project wishes to thank the publishers and authors of the articles which follow for their permission to reprint these works.

GENERAL READING - INTERDISCIPLINARY

The Flaming God, by Isaac Asimov. Saturday Review, October 30, 1976, pp. 16-19. (© Saturday Review, 1976. All rights reserved).

. . . The sun and its daily and seasonal movements have been the subjects for mythology in many ancient cultures.

HEATING & COOLING

David and Cynthia Edney: Solar Assisted Heat Pump by Edward Moran. Popular Science, October 1977, pp. 84, 86. (Reprinted from Popular Science with permission © 1977 Times Mirror Magazines, Inc.)

. . . Using a solar collector, a heat pump, and fireplace in varying combinations has led to substantial fuel savings in a modest-sized home.

Ground Water Heat Pumps - Home Heating and Cooling From Your Own Well by Robert Gannon. Popular Science, February 1978, pp. 78-82. (Reprinted from Popular Science with permission © 1978 Times Mirror Magazines, Inc.)

. . . Ground-water heat pumps offer potentially economical heating and air-conditioning services to the careful investor. Problems and benefits are itemized and diagrams are included which explain the physical operation of the heat pump.

Solar Energy: Wave of the Future by Daniel I. Levy. Journal of Property Management, July/August 1976, pp. 151-154. (Reprinted from Journal of Property Management July/August 1976, with the permission of, and copyrighted by, the Institute of Real Estate Management of the NATIONAL ASSOCIATION OF REALTORS ®).

. . . Solar energy collection systems and their limitations are described the state of the field is explored.

Solar Thermal Energy: Bringing the Pieces Together by William D. Metz. Science, August 12, 1977, pp. 650-651. (Reprinted from Science with permission © 1977 American Association for the Advancement of Science).

. . . Explores solar collection systems designed for intermediate temperature systems. Many examples of cost comparisons are provided.

ELECTRICAL PRODUCTION

Energy From The Sea, Part II by Arthur Fisher. Popular Science, June 1975, pp. 78-81, 122. (Reprinted from Popular Science with permission © 1975, Times Mirror Magazines, Inc.)

. . . The thermal gradients of our oceans offer a rich potential source of electricity and one which available technology is ready to exploit.

Power From The Sea by Mark Swann. Environment, May 1976, pp. 25-31. (Reprinted from Environment with permission © 1976, HELDREF Publications).

. . . Sea thermal electrical generation may well be a viable source of energy in the next few decades. Mechanical economics, construction, and environmental factors are addressed.

Power With Heliostats by Alvin F. Hildebrandt and Lorin L. Vant-Hull. Science, September 16, 1977, pp. 1139-1146. (Reprinted from Science with permission © 1977 American Association for the Advancement of Science).

. . . A thorough analysis of the solar power tower concept, including its planning, design of components, storage principles, and economic considerations.

Solar Cells Find Their Niche In Everyday Life On Earth by David Morris. The Smithsonian, October 1977, pp. 39-45. (Reprinted from The Smithsonian with permission © 1977 Smithsonian Institution).

. . . New technological breakthroughs will bring the per kilowatt-hour costs of electricity, generated by solar photovoltaic cells, within reach of industry and eventually the homeowner.

BIOMASS CONVERSION

Energy From Wood Wastes by Paul N. Cheremisinoff and Angelo C. Morresi. Environment, May 1977, pp. 25-31. (Reprinted from Environment with permission © HELDREF Publications.)

. . . Wood wastes can potentially provide a significant source of energy for heating, and raw materials for pulp and product development. Technical and economic details are provided.

Green Plants As Solar Energy Converters by Lois R. Ember. Environmental Science and Technology, June 1976, pp. 526 & 528. (Reprinted with permission from Environmental Science and Technology, June 1976. Copyright by the American Chemical Society.)

. . . Economic, technological, and environmental factors make fuels and foods from wastes and biomass viable alternatives to fossil and nuclear fuels.

BIOMASS CONVERSION - CONTINUED

Green Plants Might Provide The Cheapest Energy of All by Gene Bylinsky. Fortune, September 1976, pp. 152-157. (Reprinted from Fortune with permission © 1976 Time Inc.)

. . . Scientists are synthetically replicating the photochemical reactions of green plants in order to produce hydrogen for fuel. Both organic and inorganic means are being tested.

Not Out of the Woods by Charles E. Calef. Environment, September 1976, pp. 17-20, 25. (Reprinted from Environment with permission © 1976 HELDREF Publications.)

. . . Biomass conversion to supply energy in proportions significant to the economic needs of the United States can be shown to require prohibitive levels of water, nutrients, and acreage.

Photosynthetic Solar Energy: Rediscovering Biomass Fuels by Allen L. Hammond. Science, August 13, 1977, pp. 745-746. (Reprinted from Science with permission © 1977 American Association for the Advancement of Science.)

. . . Biomass conversion may constitute a major source of energy in the near future. Field crops, forest wastes, and aquatic plants are potential biomass sources. Increasing photosynthetic efficiency is another approach.

PRACTICAL APPLICATIONS - HOW TO BUILD

Five Solar Water Heaters You Can Build by Edward Moran. Popular Science, May 1976, pp. 99-103. (Reprinted from Popular Science with permission © 1976 Times Mirror Magazines, Inc.)

. . . Specifications for the construction of five different types of solar water heaters are provided along with performance details.

John DesChenes: Corrugated Plate Window Collector by Edward Moran. Popular Science January 1978, pp. 24, 26, 116. (Reprinted from Popular Science with permission © 1978 Times Mirror Magazines, Inc.)

. . . Construction details are given for a window solar heat collector which has low expense and a fast pay-back period.

SOCIAL AND ECONOMIC IMPLICATIONS

Kilowatts From the Sky by Peter Britton. The Lamp, Summer, 1976, pp. 16-21. (Reprinted from The Lamp © 1976 Exxon Corporation.)

. . . Solar energy is being increasingly employed in the United States. This article is a broad overview of the subject with many examples.

Soft and Hard Energy by Nicholas Wade. The New Republic, February 25, 1978, pp. 25- . (Reprinted from The New Republic with permission © 1978, The New Republic.)

. . . Two paths lie ahead as alternatives in meeting United States energy needs: the "hard" route involving centralized high technologies and the "soft" path involving alternate energy sources such as the sun and wind.

Solar Energy Research: Making Solar After the Nuclear Model? by Allen L. Hammond and William D. Metz. Science, July 16, 1977, pp. 241-243. (Reprinted from Science with permission © 1977 American Association for the Advancement of Science.)

. . . The present fiscal allocations to solar energy research may be the least economically viable for future applications to home and industrial use. Political and technical issues are summarized.

The Sun in a Drawer by Bruce Anderson. Environment, October 1975, pp. 36-41. (Reprinted from Environment with permission © 1975 HELDREF Publications.)

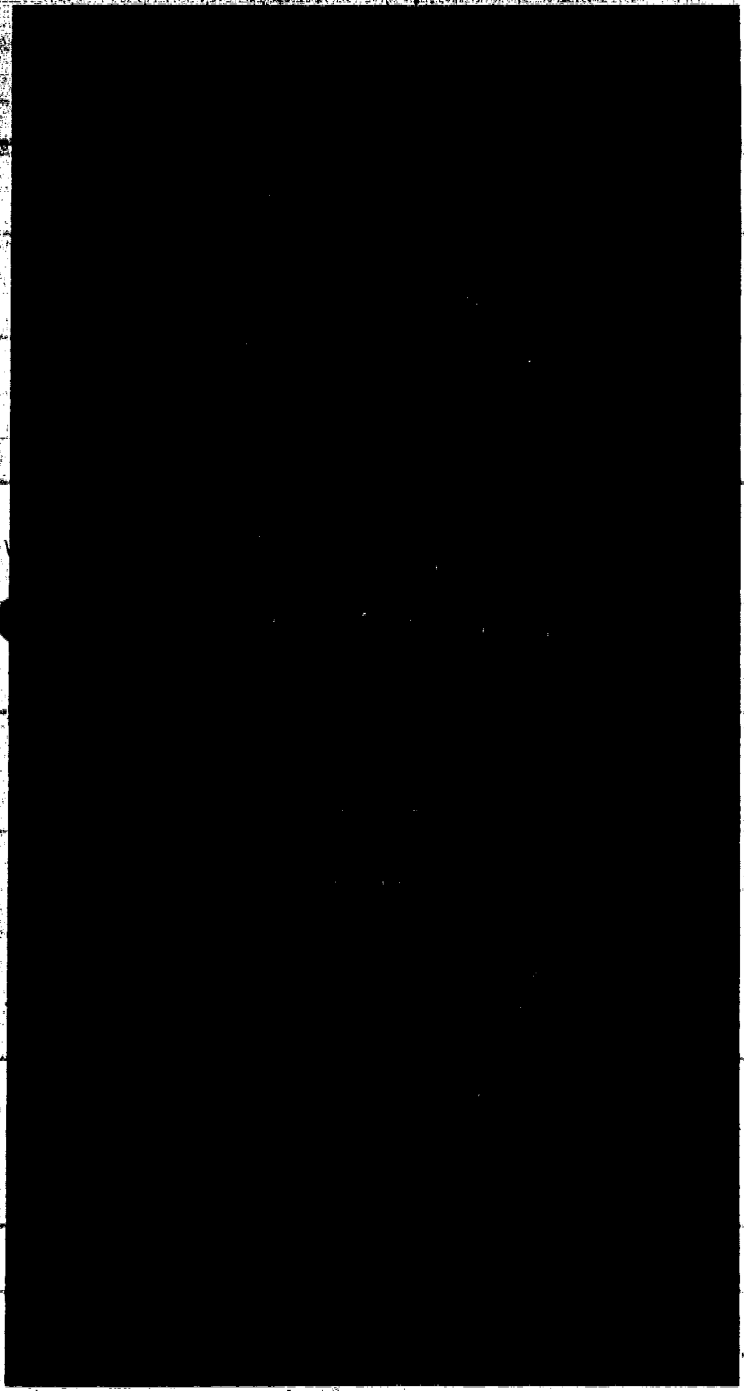
. . . Extensive use of solar energy will require surmounting a host of manufacturing problems and overcoming present restrictions and regulations involving building codes, tax laws, mortgage criteria, and labor requirements.

Tinkering With Sunshine by Tracy Kidder. Atlantic Monthly, October 1977, pp. 70-83. (Copyright © 1977, by The Atlantic Monthly Company, Boston, Massachusetts. Reprinted with permission.)

. . . The potential of solar energy for heating and electrical power is being proved by numerous scientists, engineers, and innovators. Important ecological, economic, and technical issues are raised in a case-study approach.

The Flaming God

Greek and Norseman, Aztec and Egyptian, all prayed to a sun-god, mythology's deity, without whom no human could live



Tomb of Irinufer, Thebes—"the god of that city became Amon-Re, god of Thebes and of the sun."

by Isaac Asimov

If you were a primitive person waiting through a long night; if it were dark and chilly, with no source of light and heat but perhaps a smoldering campfire; if you could hear the rustling noises that might mean predatory animals that could see far better in the dark than you could; if you could sleep no more—what would be the greatest sight?

It would have to be the soft graying of the sky in the east, the brightening of the dawn, which brought the sure promise that, in a short while, poking above the horizon, would come the sun itself, to make the world light and warm and secure again.

In those days, when the workings of the universe were attributed to myriad gods, surely among the chief of them would have to be a sun-god, powerful and beneficent, for how could human beings live without the sun? God's first command in the Bible was "Let there be light" (to be collected into sun, moon, and stars on the fourth day), for without light nothing else was possible.

To the ancient Egyptians, the sun-god was Re, and he was the principle of creation, creator of everything, even of himself. Each Egyptian city had its own god, often equated with the sun-god. When the Egyptian empire was at its height, about 1500 B.C., with its capital the southern city of Thebes, the god of that city, Amon, became Amon-Re, god of Thebes and of the sun.

Then, about 1360 B.C., when for the first time in history, as far as we know, a monotheistic religion was established briefly under Pharaoh Ikhnaton, of Egypt, the one supreme god he worshiped was the god of the sun.

The equally old Babylonian civilizations had a sun-god called Shamash, the giver of life and light, and the father of law and justice. And why not? It's natural even today to equate law and justice with the light of the sun and to feel that the cloak of darkness hides evil and crime.

Every civilization had its sun-god among the great powers of the pantheon. India had the redheaded Surya, from whom the race of human beings was descended. Japan had Amaterasu (unusual in being a sun-*goddess*), and if she was not the ancestress of the human species, she was at least the progenitor of the Japanese ruling house, of which Hirohito is the current representative.

The Norse had the beautiful Balder, god of the sun, of youth, and of beauty, who was married to Nanna, goddess of the moon. And so it goes: the ancient Irish had Lugh; the ancient Britons, Lleu; the ancient Slavs, Dazhbog, who

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A trained biochemist, Isaac Asimov is an unrestrained author who has written a galaxy of articles and more than 170 books. His latest: a collection of mystery short stories entitled More Tales of the Black Widowers.

was also the god of wealth and success—undoubtedly because of the sun's golden appearance; the Polynesians, Tane, who was also the god of all living things; the Maya, Itzamna, the sun-god who was the first, the oldest, and the creator of all else; the Aztecs, Quetzalcoatl, a sun-god who was also the god of wisdom and the inventor of the calendar.

In the West, however, the best-known sun-god is the Greek Helios, who was later identified with Apollo. Whereas the Egyptian sun-god, Re, crossed the sky in a boat, Helios crossed it in a magnificent golden chariot drawn by four fiery horses that only he could control.

The difficulty of keeping those raging steeds on their course was the thought that gave rise in Western literature to what is perhaps the best-known myth involving the sun-god: Helios had a son, Phaëthon, by the nymph Clymene. When doubts were cast on his paternity, Phaëthon went to Helios and insisted that the god vow to vindicate his son's honor. Helios vowed, and Phaëthon demanded to be put in charge of the solar chariot for a day.

Culver

Helios—"fiery horses only he could control."

Helios was forced to give in, and Phaëthon took the controls. Feeling an inept hand on the reins, the horses went out of control. Rearing and plunging, they came too close to earth, burned a desert across northern Africa, and baked the African peoples black. The earth would have been destroyed if the Greek master god, Zeus, had not struck Phaëthon out of the chariot with lightning and allowed the horses to return of their own accord to their accustomed path.

The normal path of the sun is itself a matter of adventure. To help use the sun and moon as bases for timekeeping, the ancient Sumerians (the earliest civilization in the Tigris-Euphrates Valley) were the first to mark off the stars into those groups we now call constellations, and they gave them fanciful names based on resemblances of the distant star configurations to familiar objects. The sun, in the course of the year, passed through twelve constellations of the zodiac, called after the names of lions, crabs, and archers.

The tale of the sun's journey would recount his victory over each danger he encountered, and the suspense would be great, for only by his victory could his course be successfully completed and human survival assured. It may be that the twelve labors that Hercules must successfully complete before achieving rest in heaven is a version of the sun's passage through the twelve dangerous constellations—a version obscured by changes in the names of the constellations and by the accretions of incidents by ancient mythmakers.

Yet the sun's career is not one of unalloyed success. However triumphant he may be ordinarily, he can be obscured by clouds. In those parts of Europe where clouds and storms are common, it may be the lightning-wielding god of the sky or of storms who is supreme—the Zeus of the Greeks and the Thor of the Norse. Even the Bible seems to depict Yahweh as having been a storm-god in primitive times.

There is also the danger of eclipse, which temporarily seems to slay, in part or in whole, either the sun or the moon. In the Norse myths both the sun and the moon are eternally pursued by gigantic wolves as they make their way across the sky, and occasionally the wolves overtake the luminaries and hide them, temporarily, within their slavering jaws.

But the storm cloud appears only occasionally, and the eclipse is even more rare. One solar death, however, is periodic and inevitable. At the close of each day, the sun, no matter how glorious its reign, must sink beneath the western horizon, defeated and bloody, and night returns in victory.

This is represented most colorfully in the Norse tale of their sun-god, Balder. Balder, the joy of gods and humanity, is troubled suddenly by a presentiment of death. His mother, Frigg (the wife of the Norse master god, Odin), exacts an oath from all things to do no harm to Balder but neglects to include the mistletoe. The gods then engage in the game of hurling missiles at Balder in order to watch those missiles swerve away of their own accord.

The evil god of fire, Loki, learning of the exemption of the mistletoe, carves a mistletoe branch into a spear and gives it to Hoder, the god of night, who, being blind (after all, one cannot see by night), has not been participating in the game. Loki guides Hoder's aim and Balder falls. The sun had died under the attack of night.

A less obvious solar myth may be the Hebrew legend of Samson. The Hebrew version of the name, Shimshon, bears a striking resemblance to *shemesh*, the Hebrew word for "sun" (itself related to the Babylonian Shamash). Two miles south of Samson's traditional birthplace was the town of Beth-shemesh ("house of the sun"), believed to have been a center of sun worship.

Samson, like Hercules, survives various dangers because of his superhuman strength. What's more, Samson's strength derives from his hair, which may be viewed as representing the golden rays of the midday sun. When Samson's hair is shorn, he grows weak, as does the sun when it approaches the horizon, red and rayless, so that it can be looked on without harm. It is in the lap of Delilah that Samson sleeps when he is shorn, and Delilah's name is closely akin to the Hebrew *lilah*, meaning "night." The sun sinks into the lap of night and is defeated and blinded. But Samson's hair grows again and he recovers his strength for one last feat, since, after all, the sun does rise the next morning.

In fact, in the sunny lands particularly, the sun must survive all the onslaughts of night and must win in the end. In Persian mythology Ahura Mazdah, the god of light, fights Ahriman, the god of darkness, in a cosmic battle that fills the universe—and it is Ahura Mazdah who will win at the end of time. (The Jews of the Persian period adopted this view, and it is from 400 B.C. onward that Satan enters the

Judaic, and later the Christian, consciousness as the dark adversary of God, to be defeated at the end.)

The sun's setting and rising is one inspiration for the many mythic tales involving the death and resurrection of a god. An even more impressive death and resurrection is the death of vegetation with the coming of winter and its restoration in the spring.

The tale of Balder might just as well be the symbol of the god of summer's being slain by the god of winter. Similar significance can be given to the death and resurrection of Osiris among the Egyptians, of Thammuz among the Babylonians, and of Proserpine among the Greeks.

But the sun is clearly connected with the summer-winter cycle as well as with the day-night cycle. Throughout the European summer, the noonday sun reaches a slightly lower point in the southern sky each day than it did the day before. As the sun's path in the sky slowly sinks southward, the temperature grows colder and the vegetation turns brown and dies.

If the sun should continue to sink and should pass down behind the southern horizon altogether, death would be universal and permanent; but that does not happen. The rate of sinking slows, and each year on December 21, by our calendar, the sun comes to a halt—solstice (from the Latin *solstitium*, "sun halt")—and thereafter begins to rise again.

The winter may continue to sharpen after the solstice, but the fact that the noonday sun rises steadily higher in the sky is a guarantee that spring and summer will come once more. The day of the winter solstice, of the birth of a new summer sun, is therefore a time for a great festival, celebrating the rescue of all life.

The most familiar solstice celebration of ancient times was that of the Romans. The Romans believed that their agricultural god, Saturn, ruled Italy during an early golden age of rich crops and plentiful food. The winter solstice, then, with its promise of a return of summer and of the golden time of Saturnian agriculture, was celebrated with a week-long Saturnalia from December 17 to 24. It was a time of unrelieved merriment and joy. Businesses closed so that nothing would interfere with the celebration, and gifts were given all round. It was a time of the brotherhood of humanity, for on that day servants and slaves were given their temporary freedom and were allowed to join in the celebration with their masters and even to be waited on.

Incas worshiping the sun—"every civilization had its sun-god in the pantheon of powers."

Bettmann Archive

Culver

Balder, the Norse sun-god—married to the moon.

The Saturnalia did not disappear. In fact, other evidences of sun worship came in the time of the later Roman Empire. Heliogabalus, a priest of the Syrian sun-god, sat on the Roman throne from A.D. 218 to 222, and about that time, the worship of Mithra, a sun-god of Persia, was becoming popular, especially among the soldiers.

The Mithraists celebrated the birth of Mithra at the winter solstice, a natural time, and fixed on the day December 25 so that the popular Roman Saturnalia could build up to the Mithraist "Day of the Sun" as a climax.

At that time, Christianity was locked in a great duel with the Mithraists for the hearts and minds of the people of the Roman Empire. Christianity had the great advantage of accepting women into the religion, whereas Mithraism rejected them (and, after all, it was the mother, not the father, who influenced the religious beliefs of the children). Mithraism, however, had the Saturnalian festival of the sun on its side.

Sometime after A.D. 300, Christianity managed the final coup of absorbing the Saturnalia, and with that it scored its final victory over Mithraism. December 25 was established as the day of the birth of Jesus, and the great festival was made Christian. There is absolutely no biblical authority for December 25 as having been the day of the Nativity.

All the appurtenances of the Saturnalia were adopted anyway—the joy and merriment, the closing of businesses, the brotherhood, the gift giving. All was given new meaning, but all was still there.

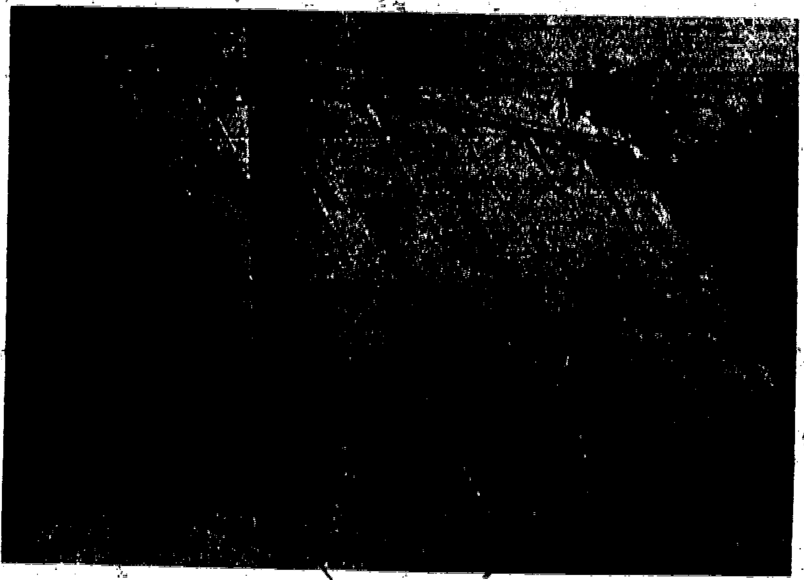
So that beneath the panoply of the celebration of the birth of the Son is the distant echo of that far older rite, the celebration of the birth of the sun. ◉

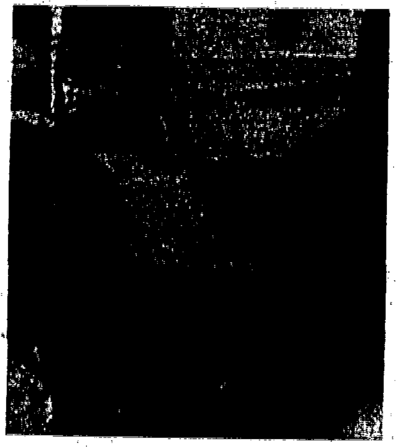
ADVENTURES IN ALTERNATE ENERGY

A monthly sampling of projects PS readers have devised to conserve or replace fossil fuels

David and Cynthia Edney, Solar-assisted heat pump

Dave Edney monitors all gauges and meters twice a day, for continuous-performance data. Edney reports solar-collector efficiency averages 60 percent.





The 280-sq.-ft. aluminum trickle collector dwarfs Cynthia Edney. Heat pump (above) is capped with insulated duct. Piping at rear brings water to and from water-heating coil in fireplace.

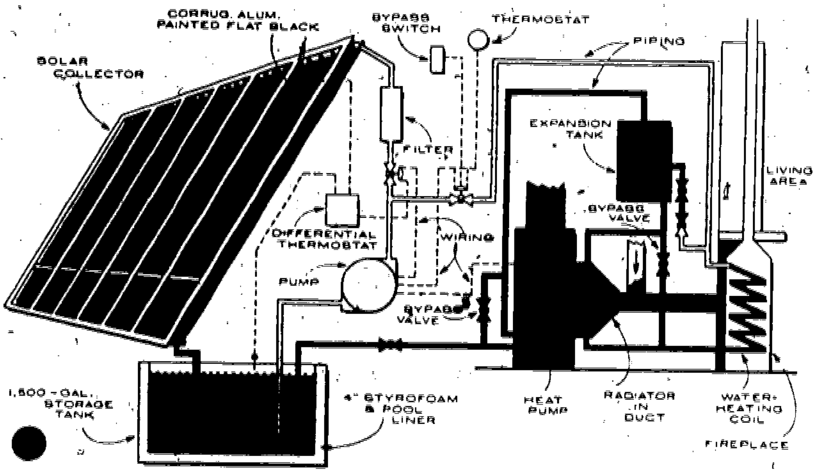
By EDWARD MORAN

Belfast, where this house is located, is on northwestern New York's "cold shoulder"—that 7000-degree-day blizzardy tract abutting Lakes Erie and Ontario. Last winter, the Edneys spent an average of 85 cents a day to stay warm in the 1128-sq.-ft. house they built themselves with selected professional help.

The *house*, complete with $7200 worth of solar and wood-heat equipment, cost Dave and Cynthia Edney about $25 a square foot. That's the going rate for a lot of solar *collectors* these days, like the ones in the "world's most advanced solar home" [PS, July]. Dave, a mechanical engineer, and Cynthia, a chemist, are convinced that a well-designed, energy-efficient house is not an impossible dream for young couples (he's 30, she's 28).

So how did the Edneys end up heating their home for $26 in January of That Winter of '77? By a judicious mix of domestic technologies, both in overall design and in the heating system itself. The house is a single-floor ranch style with two bedrooms and a family room. It's slab-on-grade, except for an excavated 12-by-12-ft. basement; a 24-by-30-ft. garage/shop is attached.

The walls of the house (post-and-beam construction, with no interior load-bearing walls) are six inches thick. The roof, nearly flat to maintain an insulating snow load in winter, has aluminum sheeting to reflect heat in summer. And it's got six inches of insulation. Grape vines planted around the west-facing porch (great-grandma knew how to keep her cool) re-



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duce heat gain on summer afternoons. The garage and shop are on the north side to shield the living area from harsh winds. A "closed-door policy," an old but oft-forgotten trick, zones heat into living areas in winter: The family room, for example, is self-contained, with wood stove and spring water for use under extreme conditions.

There are three major components to the Edneys' heating system: a York solar-assisted heat pump; the flat-plate trickle collector that supplies the pump; and a backup fireplace, complete with outside venting and water-heating coil.

The heat pump extracts heat from the solar-heated water and supplies that heat to the forced-air system using a refrigeration cycle. The process is reversible to provide cooling in summer. When water temperatures are between 45° and 85°, the heat pump comes on line. Above 85°, the house is heated directly by water through a radiator in the forced-air duct (see diagram); below 45°, the fireplace supplies auxiliary heat.

The fireplace is equipped with heavy metal doors that can be closed for good draft control. Air preheated around the firebox supplements the heat pump, and water from the coil is pumped to the solar storage tank to replenish the supply, or can be used for domestic hot water. The fireplace supplied about 16 percent of the total heat requirements last winter. Its combustion air is supplied from the outside, a sensible setup: Why waste indoor air you've paid to heat when the fire could do just as well with colder air?

The drain-down collector on the south wall is corrugated aluminum sheet painted flat black and double-glazed with acrylic, with four inches of Styrofoam insulation behind. Water trickles over the 280-sq.-ft. collector at a rate of 25 gpm and flows into a below-ground 1500-gal. concrete tank that provides about two days' storage.

The Edneys estimate that it would have cost $284 to heat their house with an electrical-resistance system last winter. "This gives us a system C.O.P. (coefficient of performance) of approximately 2.33," they say.

The table below indicates performance data for the last heating season. To ask a specific question, send a stamped return envelope to the Edneys, c/o Belfast Specialties Co., P.O. Box 501, Belfast, N.Y. 14711. ▣

Performance data 1976-1977

Month	Collector run. time (hr.)[2]	Monthly heat requirement (Btu)[1]	Degree days in month	% heat supplied by solar[2]	Operating cost of system[3]
Dec.	87.5	6,799,360	1328	84	$26.79
Jan.	128.5	7,823,360	1528	80	28.96
Feb.	141.1	5,002,240	977	96	28.50
Mar.	145.3	3,527,680	689	100	21.05
Apr.	72.4[4]	2,370,560	463	100	16.72

[1] House heat loss at 10° 5120 Btu/degree day

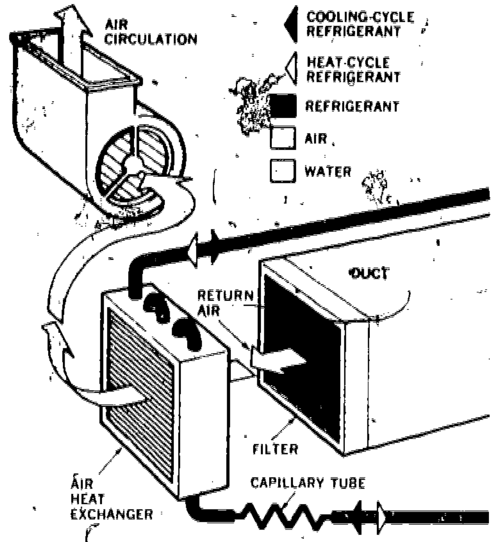
[2] Total hours of auxiliary heat required, divided by hours in month

[3] Figured from electric meters on heat pump and water pump, and from hour meters, based on electric rate per kilowatt hour

[4] Reflective aluminum covers were installed on April 13, when storage temperature reached 145°. System was shut down from this point, except for the heat pump. Covers will be in place until early October; heat will be provided from storage or from the fireplace until then.

Ground-water heat pumps

–home heating and cooling from your own well



If you're sitting on "good" water you may cut your fuel bills dramatically

By ROBERT GANNON

If you're building a home or just planning to replace your furnace, a ground-water heat pump may be what you're looking for.

A what?

A ground-water heat pump is a device that cools water usually from a well and then pumps the extracted heat into your home. In summer, it withdraws heat from the inside air and uses water to carry it away.

Do you have a large supply of good water, live in a reasonable climate, and plan to install central air-conditioning as well as a new furnace? If so, you could use a ground-water heat pump and chop a third, a half, and maybe even more from your heating and cooling bill.

The idea works. Good equipment is available. It ordinarily requires little maintenance, costs not much more than conventional furnaces, and amortizes itself in only a few years.

So why aren't more people using the system? The question has a number of answers, and they're confusing. Ask someone in the trade about ground-water heat pumps and you're likely to get answers that are uninformed, misinformed, or downright wrong.

To try to arrive at the truth, I've spent the last few months talking with researchers, manufacturers, contractors, engineers, and homeowners.

Finally, I believe I've sorted out the main factors, and I've arrived at a conclusion: If you can use one, go ahead. You'll probably save yourself a heap of money. But that *if* is a muddy one.

First, some background: Most homeowners know at least something about conventional heat pumps, the air-to-air or air-source models [PS, Oct. '73, Sept. '76]. Essentially, they're air conditioners that can reverse. In summer they cool the house; in winter, they warm it by extracting heat from the outside air.

And the beauty is that when the outside temperature is moderate, the only cost is for the electricity to run the heat pump's compressors and fans there's no burning of fuel. Such systems can be extremely efficient. Heating units are rated by their coefficient of performance (COP). This is based on electrical-resistance heating in which one kilowatt provides 3412 Btu in an hour, for a COP of one. A heat pump not only produces heat, but moves it from one place to another, so the COP of an air-source system can be much higher than one, even three, when the outside temperature is around 50°F. In other words, for each watt of electricity consumed by the unit, three watts of heat energy are available for warming the house one from the unit, two from the outside. And the electric heating bill drops by two-thirds.

But the efficiency of air-source systems plummets as the outside temperature falls. As temperatures approach freezing, such severe

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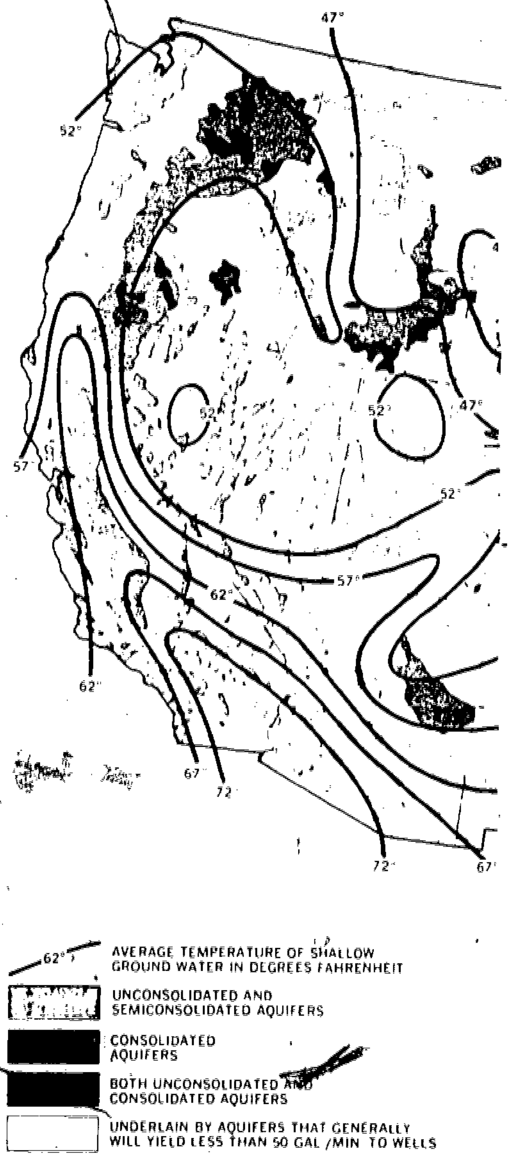
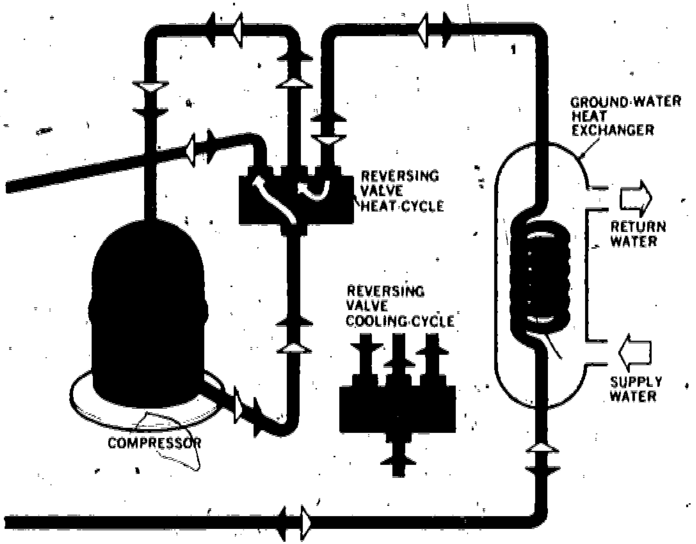
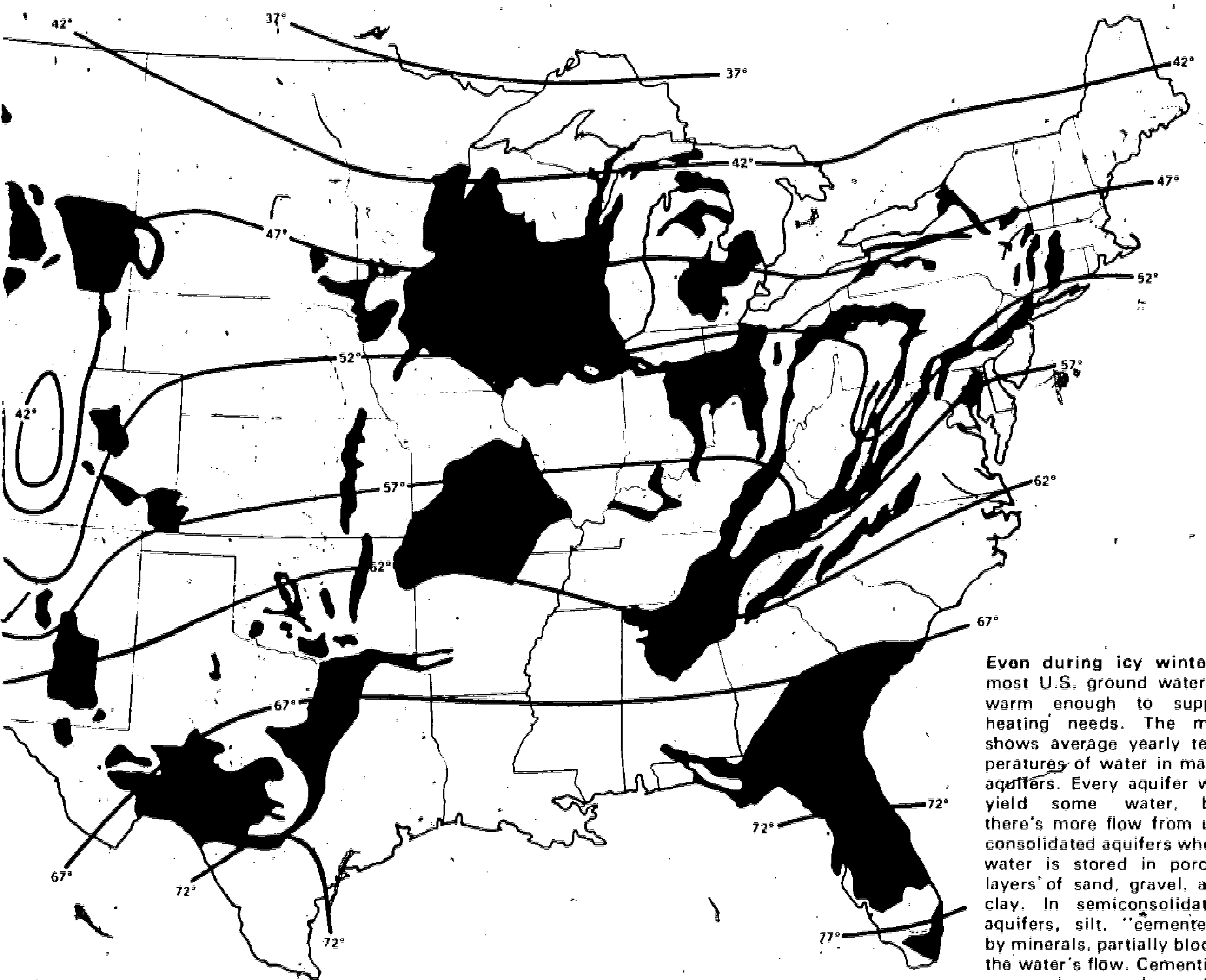
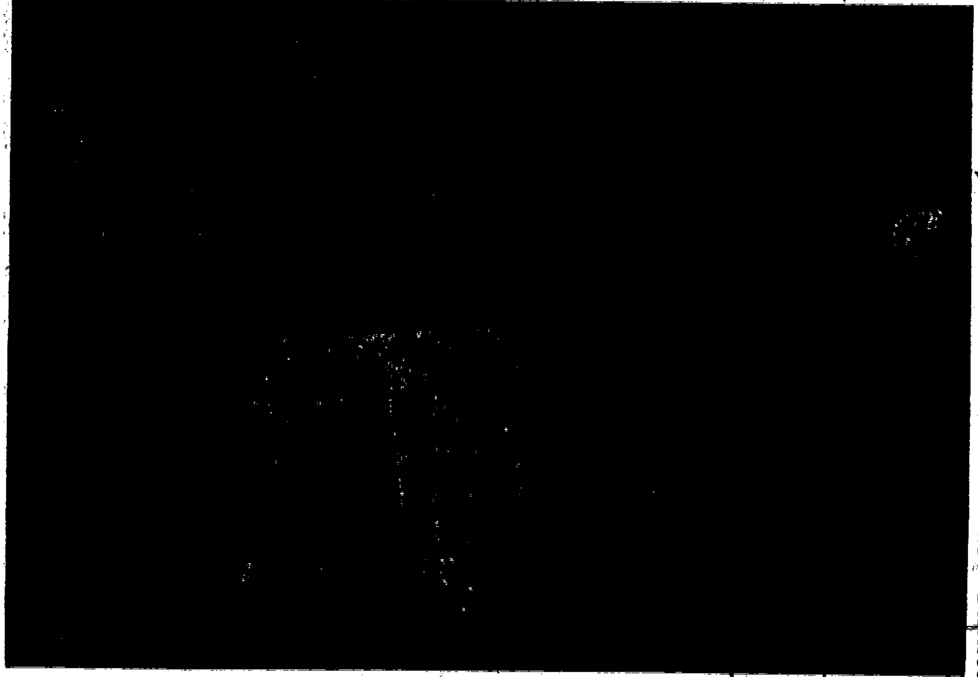




Like an air conditioner, a ground-water heat pump uses circulating refrigerant to absorb heat. Unlike an A/C, heat is absorbed from water, not air, and is released inside the house. In a typical heating cycle, liquid refrigerant flows through a capillary tube that lowers its pressure and boiling point. Passing through the ground-water heat exchanger, the refrigerant extracts heat from the circulating water, boils and vaporizes. The cooled water returns to the ground while the warm, low-pressure gas travels to the compressor. There it's squeezed to form a high-pressure, hot gas. Pumped through a reversing valve to the air heat exchanger, it condenses, releasing heat to the circulating air. The warm air is ducted throughout the house, and the liquid refrigerant flows back through the capillary tube to repeat the cycle. For cooling, the process reverses. The compressor sends the hot gas directly to the water heat exchanger to release heat collected from the house. The warmed water returns to the ground while the cooled, liquefied refrigerant flows through the capillary tube to the air heat exchanger. There, it again absorbs heat from the house and vaporizes. The gas returns to the compressor, which pumps it back to the water heat exchanger to renew the cycle.



Even during icy winters, most U.S. ground water is warm enough to supply heating needs. The map shows average yearly temperatures of water in major aquifers. Every aquifer will yield some water, but there's more flow from unconsolidated aquifers where water is stored in porous layers of sand, gravel, and clay. In semiconsolidated aquifers, silt, "cemented" by minerals, partially blocks the water's flow. Cementing process is more advanced in consolidated aquifers.



ROSLYN B. ALBERT

Dr. Carl Nielsen shows off the ground-water heat pump he designed and built in 1955. Today, it still provides efficient heating and cooling for his 2000-sq.-ft. home. Behind him, heat-exchanger pipes circulate well water and refrigerant. Constant-temperature water acts as winter heat source, summer heat sink.

strains are put on the units that they automatically switch in resistance heat. A similar problem arises in summer when temperatures edge into the 90's. As the amount of electrical energy needed to move heat outside mounts, the efficiency of air-source units dives.

An ideal situation, of course, would be one in which outside air remains at a constant temperature.

And that's where ground water comes in. Unlike air or surface water, ground water (from a well or spring) has a stable temperature: the mean annual temperature of the overlying air (see map). In winter, ground water is always warmer than the air; in summer, always colder.

So you drill a well and tap this water, using it as a heat source in the winter, a heat sink in summer. Simple.

The idea isn't new. The concept has been kicking around since not long after World War II. But hardly anybody outside the Deep South has been interested—for largely the same reason that you didn't hear much about solar collectors before the oil embargo. Conventional home heating was cheap. Why experiment?

Ground-water pioneers

One who did experiment is physicist Carl Nielsen, a professor at Ohio State University ["Solar Ponds," PS, Dec. '77]. He has one of the oldest continuously operating water-source heat pumps on record.

"I learned the principle of heat pumps when I was a physics student," he told me. "So when we first built, in 1948, I decided to try a water-source pump. It's clean, I thought; it doesn't produce soot; I don't have to put up a chimney. And it's relatively quiet; I didn't want an oil furnace that would roar at me."

No commercial ground-water heat pumps were available 29 years ago, so Nielsen devised his own one-ton unit, using standard refrigeration-plant parts, except for the heat exchanger. "For that, I took two lengths of pipe—a one-inch-o.d. piece and a ⅝-inch-o.d. piece—pushed one inside the other, then coiled them up. Worked fine."

> **"**So you drill a hole and tap this water, using it as a heat source in the winter, a heat sink in summer. Simple**"**

He drilled an 80-foot well in the backyard, determined that the 44-degree water had a sufficient flow, and ran his outflow to a pond alongside the house. The outflow, by slow percolation, would eventually return water to the well.

The unit ran for seven years with no trouble. So when he built a larger house on the same property, he again planned for ground-water heat. This time he built a two-kW unit. It's been running ever since, for more than two decades now. And the problems he's had over the years can be narrowed to one: About ten years ago a starter relay burned out.

One severe problem, I had heard, is scaling; another is encrustation. In the beginning, Nielsen was concerned, too. His well water is extremely hard and rich in iron. "If you fill a jar and let it stand for a day, it turns brown," he said. "I wondered what it would do to my coils." Nielsen unbolted the end of his heat exchanger. "Here; stick your finger in." I did—and got only a light brown smudge of oxidation. "The coil was built so that any buildup of scale could be cleaned out," he said, "and I bought a wire brush to be used with my hand drill. But here it is, unused." After 22 years.

When Nielsen installed his pump, oil in Columbus was 15 cents a gallon, electricity two cents a kWh. Now electricity stands at three cents a kWh, while oil has zoomed to 51 cents a gallon. "With the 3.5 COP I'm getting, the crossover came when oil hit about 25 cents," he said. "At that point the pump was no longer simply an experiment; it was a money saver."

Pumping into a think tank

While heat-pump engineers over the years have largely ignored single-family residences, they have developed effective ground-water systems for large buildings. Not far from the Nielsen home, in downtown Columbus, is Battelle Institute, a scientific think tank. A 317,000-square-foot section of the sprawling complex is heated and cooled entirely by heat pumps—probably the largest setup of its kind in the country. Battelle gets its water, at 54°F, from five 16-inch wells drilled to 50 feet in a sand-and-gravel aquifer, and each month pumps some 40 million gallons through the exchanger and out into nearby Olentangy River, which supplies the aquifer.

The massive equipment works pretty much the same as the unit in Dr. Nielsen's basement, but the physical difference is striking. Nielsen's setup is stuck off in a dingy recess and takes up about as much

disappearing and oil prices surging, ground-water heat pumps make sense

space as a freezer. Battelle's controls alone occupy a complete room —its walls decorated with huge flow charts and lined with digital counters flicking remote readings.

Battelle developed the system in the days of cheap energy, simply because its engineers were intrigued with the idea. Today, it's one of the best examples around of how efficient ground-water heat pumps can be: The heating COP in one of the buildings is 5.4.

In the 20 years since Battelle installed its systems, ground-water heat pumps have become commonplace in large buildings: They now number in the thousands.

But home units haven't kept pace. Now, though, some experts see a dramatic growth on the horizon. Says Charley Smith, a spokesman for York Division of Borg-Warner: "Quite frankly, until the energy situation turned around, sales of our water-source units were marginal, but they're really starting to pick up now." And at least two manufacturers, WeatherKing and Vaughn, predict that sales will double.

Just how much can today's homeowners hope to save with a ground-water heat pump? In a 1976 study prepared under a grant from the U.S. Environmental Protection Agency, the National Water Well Association stated that "at present prices, a homeowner can have his investment for a [water source] heat pump returned from cost savings resulting from reduced energy consumption in four to eight years [compared to] conventional heating and cooling units" (see box).

With natural gas disappearing, oil prices surging, and coal largely unacceptable to most Americans, ground-water heat pumps seem to make sense. But if so, why don't many more homeowners have the units? The objections, I've found, boil down to five.

Problems: real and imaginary

- You need a well. "Sure, it's an effective device and an energy conserver *if* you've got the water," says Ben Sienkiewicz of the Air Conditioning and Refrigeration Institute (ACRI). "But how many of us have a well in our yard?"

A few families are using lakes, rivers, or canals, but for most homeowners, a well is necessary. And that means an average of about $2000 in drilling costs, according to the National Water Well Assn.

Heating System		Initial cost	Annual amortization	Annual fuel cost	Annual heating cost (nearest $25)
Gas furnace		$ 700	$ 85	$308	$ 400
Oil furnace		1400	170	475	650
Coal furnace		1400	170	425	600
Electric furnace		900	110	880	1000
Air-source heat pump	(a)	3000	456	463	925
w/air cond.	(b)	800	122	463	575
Ground-water heat pump	(a)	3000	456	275	725
w/air cond.	(b)	800	122	275	400

Physicist Nielsen worked out the table above using figures gathered in Columbus, Ohio, during the winter of 1977. The figures are probably typical of costs throughout the central belt of the U.S.

The table assumes an annual heating requirement of 100 million Btu. Nielsen assumed an annual average COP of 3.2 for the ground-water heat pump and 1.9 for the air-source heat pump, and estimated high for the initial cost of this equipment. For fuel costs, he figured gas at $2 per 1000 cu. ft., oil at 42¢ a gal., coal at $80 a ton, and electricity at 3¢ per kWh. Fuel efficiency is rated at 65 percent. Amortization was computed at nine percent interest over a lifetime of 15 years for the furnaces, and 10 years for the heat pumps (though Nielsen says 10 years is probably too short). Maintenance, repairs, and well-drilling costs aren't included. Among the variables are equipment condition, design, manufacturer and installation, plus weather and ground-water temperatures—so the figures are approximations only.

At first glance, it might seem as if ground-water heat pumps offer clear savings only over electrical-resistance heating. But, comparing line (b) with line (a) makes the picture clearer. Line (a) is the homeowner who doesn't install central air conditioning. Line (b) is the homeowner who installs an air-conditioning system as a matter of course (common practice in the South and West) no matter what type of heating unit is used. In this case, the $800 initial cost is the price of adding heating capability to a central air-conditioning unit (i.e. a central air conditioner would cost about $2200—for $800 more you can get a ground-water heat pump for both heating and cooling). Since $800 is lower than you'd pay for most furnaces, and since annual operating costs are so much less than those for conventional systems, the savings are substantial.

You'll need a minimum flow of about 2½ to three gpm per 12,000 Btu needed. Your chances of getting that are good.

Hydrologist Jay Lehr, executive director of the National Water Well Association, says that if you randomly sink holes to two hundred feet, about 80 percent of the time you'll find a flow rate of three gpm or more. But you may need another well to return the water to the aquifer.

Heat-pump users with an unlimited supply of water often dump the outflow into a creek or pond, or even into the nearest sewer. The movement, though, is toward recharging: returning the water—slightly warmed or cooled—to the ground via a second well. In Bexley, Ohio, two next-door neighbors each drilled a well and now share them, drawing from one and discharging into the other. If the water ever begins to run low, they'll simply reverse the flow.

Actually, the discharge well needn't be a conventional drilled well, complete with casing. A bored hole that's filled with coarse gravel to keep the sides from caving in and that's two or three feet in diameter and 20 or 30 feet deep (depending on the percolation rate) costs only about a fifth as much as a drilled well. And some people use the outflow to fill ponds or simply to water grass—a form of recharging.

- Ground water is mysterious. "There's a built-in prejudice against ground water simply because you can't see it," says hydrologist Lehr. "The reason air-source heat pumps are so widespread is not that they're better. They're not. It's simply that air is right there, surrounding us. You're not really sure the unseen ground water is there."

As evidence of this prejudice, Lehr points out that Americans use three times as much surface as ground water, even though the cost of developing ground-water supplies is only one-tenth that of reservoirs.

- High initial cost. A heat pump, either water- or air-source, costs at least fifty percent more than a conventional furnace. Add to this another $1500 to $2500 for a well and you've doubled the initial investment. In addition, your ductwork will have to be larger if you use forced-air heat. A furnace delivers air that's 160°F. A heat

Continued

pump delivers air at only about 120°, so it must move a larger volume. You need about twice the normal-size ducts (or double the number) to accommodate the flow, with a larger fan turning at fewer rpm. A faster fan with the same ducts won't do; the efficiency would drop, the noise increase.

Similarly, hot-water baseboard tubing must be able to handle about twice the volume, or have twice the tube surface exposed to the air.

State of the industry

- Nobody's pushing the idea, except a few small manufacturers, well drillers, and isolated engineers.

"Ninety-five percent of the population has never heard the term 'heat pump,'" says Paul Sturges, a Stone Ridge, N.Y., heating-cooling consultant. "And the concept of a ground-water heat pump is as foreign as, oh, heating with cow dung or antimatter."

In fact, few heating contractors have studied ground-water heat pumps. They're unfamiliar with the fundamentals of ground water and vaguely uneasy working with something 50 feet under the surface.

Even the manufacturers aren't pushing the idea. Makers are either relatively small and regional, or they produce a whole line of heating equipment, including the big money-making air-source units. Says ACRI's Sienkiewicz: "The volume of water-source pumps is so damn small, and the rest of the industry is in the hundreds of millions of dollars—you devote your time and effort to the high-volume business."

- Some water is unusable. There are two problems here: temperature and quality. The colder the water the more work the pump must do in the heating cycle. Cool water cuts the COP and requires a larger pump and compressor.

Until recently, most manufacturers limited sales to areas where ground water is at least 60°F—and that eliminates most of the upper two-thirds of the country.

WeatherKing general manager Jim Brownell says that his company is gradually extending its range "while we gain experience in what low water temperatures the units can really stand." He recommends that no unit be installed in water below 55°F without a protective thermostat to turn it off if the ground water approaches freezing.

Physicist Nielsen blames the manufacturers, calling the cold-water question a "pseudo-problem." He adds: "The notion that it's difficult to design for low temperatures is just so much baloney—and a fail-safe system that turns itself off if water pressure falls is very simple to include. I did it myself."

Vaughn Co., for one, has designed its standard models to operate with water as low as 40°F, while special units are available to handle water near freezing. Some equipment, in fact, pumps water from frozen-over lakes. But because of heavy-duty components and other extras, Vaughn models, installed, cost about a third more than those of most other manufacturers.

> "It's clean; it doesn't produce soot; I don't have to put up a chimney. And it's quiet"

The other water problem, and by far the most controversial, is quality. Iron, calcium, and magnesium salts, hydrates, suspended solids—all can result in corrosion and scale or encrustration.

What are your chances of finding unsuitable water? Robert Ross of the Better Heating-Cooling Council estimates that unusable water will be found under 15 or 20 percent of the land in the U.S.

If your property happens to fall into that group, you may be headed for disaster. One Austin, Tex., contractor will never try a water-source heat pump again: "I've had nothing but bad experiences with them; I put in three units and had so much trouble with scaling that I eventually decided to abandon them."

And in Sarasota, Fla., some homeowners must flush the refrigerator coil with acid every year or two to wash out scale, and eventually the acid itself eats through the tubing. (Strangely, almost no residential units have coils designed the way physicist Nielsen's are—so that they can be cleaned with a wire brush.)

One way to prevent scale is to use cupronickel instead of copper tubing. Some manufacturers sell it for an extra charge; a few provide it as standard. Essentially what happens, says Vaughn's Pirrello, is that the cupronickel expands and contracts with temperature, and its surface tends to flake off mineral deposits and scale with each cycle.

Design could have a lot to do with scaling, too. At least that's what Pirrello claims. The main problem, he says, is caused by internal baffles and fins—which the Vaughn unit doesn't have. What percentage of water does he find unusable? "Essentially, none."

If you decide to look into the possibilities for your home, how can you make a decision? First, you should get some idea of what a well in your yard might produce in the way of volume and quality. One way to determine potential is to ask a large, local well driller for an estimate—usually a free service. (The National Water Well Association has offered to give readers names of knowledgeable drillers in their areas. For address, see end of article.)

Local water-softening people might also have some thoughts. A plumber who deals in water heaters could give you an idea of how much scale he's finding. Engineer Owen suggests that if your neighbor has a well, get the water tested at Sears or by the local public health office. Ideally, he says, the pH should be between six and eight, and the hardness reading (on the standard scale of 0-30) no higher than 10.

Next step: Call in a heating-cooling contractor, preferably one with considerable ground-water heat-pump experience. Ask him for the names of some of his heat-pump customers and see how satisfied they are.

The results of your research should help you decide if a ground-water heat pump is for you. Conflicting claims, lack of thorough scientific studies, and the fact that technical expertise is limited to only a few people, makes its installation, in my opinion, still something of a gamble. Nevertheless, because I know that my 55-degree water is fairly soft, when my oil-guzzling furnace begins to fail, I plan to take that gamble. Maybe even sooner.

FOR FURTHER INFORMATION

American Air Filter Co., Inc., 215 Central Ave., Louisville KY 40208; **Better Heating and Cooling Council**, 393 Seventh Ave., New York NY 10001; **Carrier Air Conditioning Co.**, Carrier Pkwy., Syracuse NY 13201; **Climate Control Div., The Singer Co.**, Somerville NJ 08876; **Command-Aire Corp.**, 3221 Speight Ave., Waco TX 76710; **Dunham-Bush**, 175 South St., West Hartford CT 06110; **FHP Manufacturing Co.**, 610 S.W. 12th Ave., Pompano Beach FL 33060; **Friedrich Air Conditioning & Refrigeration Co. (Climate Master)**, 2000 W. Commercial Blvd., Ft. Lauderdale FL 33309; **Koldwave Heat Exchangers, Inc.**, 8100 N. Monticello, Skokie IL 60076; **National Water Well Association**, 500 West Wilson Bridge Rd., Worthington OH 43085; **Vaughn Corp.**, 386 Elm St., Salisbury MA 01950; **WeatherKing Inc.**, 4501 E. Colonial Dr., Orlando FL 32814; **York Division, Borg-Warner Corp.**, Box 1592, York PA 17405.

As an alternate source of energy, solar energy looks highly promising.

SOLAR ENERGY: Wave of the Future?

by Daniel I. Levy

The fuel crisis of 1973-1974 totally focussed the world's attention on the mammoth energy problems we face today. The shortages in energy came about simply because we were using more energy than we were producing. In other words, the demand exceeded the supply.

To make up for these shortages the United States started to import oil from foreign countries. Although importing this oil originally started decades ago in small quantities, today this has increased to millions of barrels of oil per year. If we continue with the present consumption we will double the amount of oil needed from foreign countries by the year 1985.

Even though we are now producing our own oil it is insufficient because much of it comes from old oil wells that have few years left of productivity. Our own oil wells cannot supply us with enough oil to keep our industries and economy running at a normal rate.

We have finally been brought to full understanding of the energy crisis because of the oil embargo. Since the oil embargo much discourse has been held on whether the shortages are imaginary or real. Even if some of the claims of the shortage are exaggerated, the fact still remains that shortages do exist and they will increase with our growing demand for this valuable fuel.

The oil embargo, therefore, created a need to find alternate sources of energy. Obviously, these sources of energy must come from within the continental United States so that foreign countries cannot control our destiny.

Our industries and commerce have been based on cheap, abundant energy sources. We consume well over 30 percent of all the oils produced throughout the world, while we only have 7 percent of the total world population. When looking within our borders for natural fuel such as oil and gas we quickly realize that the supply cannot possibly satisfy our demand. Even with a reduction in the amount of needed fuels, alternate sources of energy must be found. One of those sources of energy is solar energy.

ALTERNATE ENERGY SOURCE: SOLAR ENERGY

Solar energy means the capturing of the sun's radiation in order to produce a transportable form of energy. The sun's radiation is captured by the means of solar devices

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Daniel I. Levy is a professional planner who has had extensive experience with solar energy research and application of solar systems into buildings. He presently resides in Woodland Hills, California.

Solar Energy

and can be used for [illegible] our hot water, our homes, and [illegible] cooling them. Utilization of the [illegible] is environmentally acceptable as compared to some alternate forms of energy sources which are not.

Solar energy is not a new science. In 212 BC, Archimedes utilized the sun's radiation to burn the sails of the Roman fleets thereby defeating them in a battle. In 1878, a solar steam engine was exhibited at the Paris fair. During the 1930's, Massachusetts Institute of Technology started experimenting with solar energy and much of the research that was conducted there is being utilized by manufacturers today.

In the past, the devices for capturing the sun's radiation were very simple and did not have the sophistication of today's devices. With the desire and determination on the part of our country to find alternate source of energy, the field of solar technology has greatly improved.

SOLAR COLLECTOR

A solar system is a relatively simple system to understand. It consists of three major component parts. The part that collects the sun is known as "The Solar Collector." The solar collector is generally mounted on the roof of a building and its primary purpose is to collect the sun's radiation. The collector generally three by seven feet in size and three to four inches thick contains a system of pipes carrying either water or air through it which is then heated by the sun's radiation. The collector is covered with one or two pieces of glass or plastic in order to retain the heat captured by the sun.

STORAGE TANK

The second component within the system is a "Storage Tank." The storage tank is generally found in a basement or sub-basement of a building and contains the stored energy to be utilized at a future date when needed.

DISTRIBUTION SYSTEM

The third component of the system is the "Distribution System," which takes the stored energy from the tank and transfers it to a point where it is needed.

To demonstrate how this system operates, let's assume we will be heating water by the solar system. The cold water is pumped into the solar collector mounted on the roof and the sun's radiation strikes the collector. As the cold water passes through the collector which contains a system of pipes, the water is heated to a temperature of between 120-180 degrees.

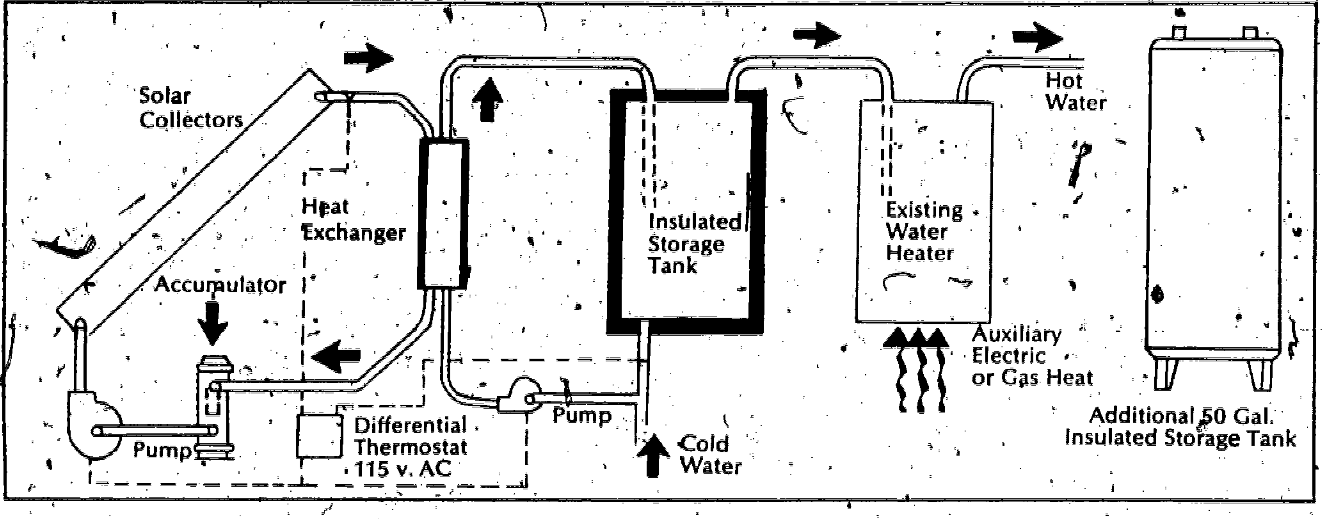
The heat generation depends on a number of factors such as flow rate and the availability of the sun's radiation. Once the water is heated it is then transferred by a system of pipes to the storage tank in the basement. This storage tank is insulated in order to retain the hot water that is collected. Finally, this hot water is then distributed in the building where needed. This hot water can either be used for domestic hot water or for the actual heating of the building. The distribution of the hot water is accomplished by a system of ducts, pipes, and appropriate values in order to take the hot water away from the storage tank and into the building.

COST OF INSTALLATION AND OPERATION

The cost of installing a system depends on the ultimate use for this system. If a system were installed in a home for heating only domestic water the cost would be approximately $1,000. Even with the solar installation a conventional backup system is needed in most parts of the country. However, a solar system can save approximately 70-80 percent of the fuel cost for heating our hot water.

Assume that it costs $25.00 per month to heat our hot water. If we install a solar we will absorb 80 percent of the cost or $20.00 per month savings and be paying $5.00 per month to utilize our conventional backup system.

The cost is more for a solar system that heats our homes, because more collectors are needed and the equipment necessary for storage is much higher. The cost will be in the neighborhood of $6,000 to $8,000 depending on the size of the home and its location.



HOW A SOLAR SYSTEM WORKS

1. The collector absorbs the sun's rays and heats a liquid that is pumped through this collector.
2. The fluid within the collector (generally antifreeze) captures heat and then transfers it to water by means of a heat exchanger.
3. The hot water is then stored for future use or can be used directly if needed.
4. Depending on location of the panels, and latitude of area, anywhere from 45 percent to 100 percent of the water can be heated by the sun.

A SOLAR SYSTEM FOR EVERY BUILDING OR HOME?

In order to derive the maximum benefits from this system, the sun's rays must face in a south or southwest direction. Not every home, of course, has this exposure. The sun's radiation may also be lost if the building is blocked by trees or other buildings. Each home must be examined by an expert to determine whether a solar system is feasible.

THE ART OF THE INDUSTRY

The industry in the last two years has grown considerably because of the demand to find alternate energy sources. Many manufacturers, distributors, and organizations are gearing up for mass production.

The most expensive item in the solar system is the solar collector. Orginally these collectors were selling for between $12.00 and $15.00 per square foot, but because of the advancements in technology and the additional competition, the price per foot is down anywhere from $4.00 to $7.00 per square foot. The efficiency is also improving so that the number of collectors needed will be reduced in the future. Because of the demand on the part of the public to produce this alternate energy source, prices and efficiencies of the collectors will come down considerably more in a relatively short period of time.

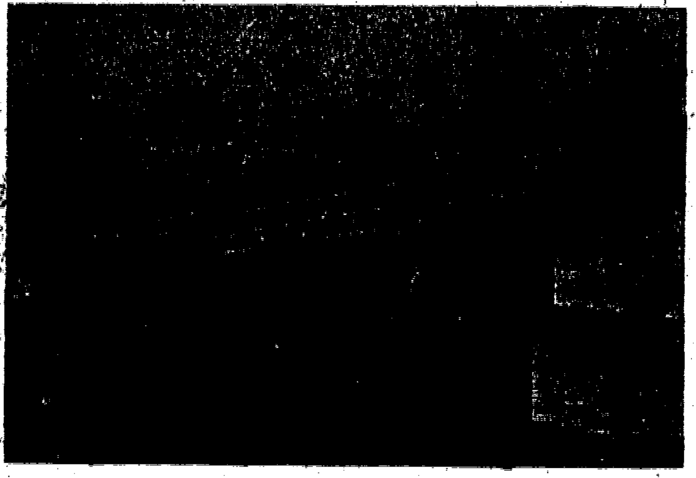
WASHINGTON INVOLVEMENT

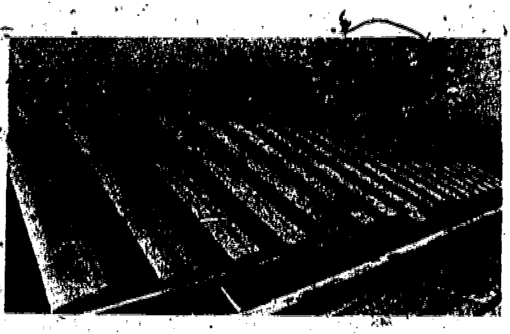
The federal government is involved with the development and experimentation of solar energy. In 1974 the Congress passed the Heating and Cooling Demonstration Act which appropriated $60 million to start experimenting and developing solar systems. A new agency known as ERDA (Energy Resource Development Administration) is in charge of overall coordination and development of the solar program. The Department of Housing and Urban Development is also involved with the solar program and has recently requested proposals to fund on an experiemental basis.

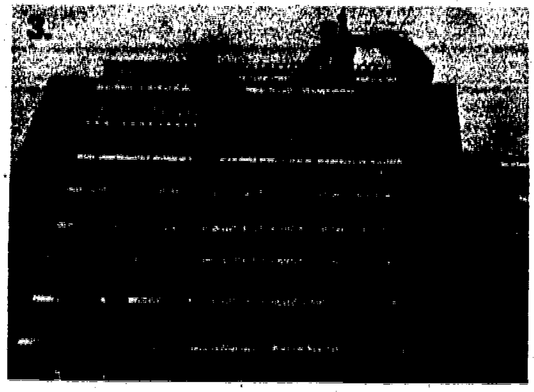
PRESENT INSTALLATIONS

There are many experimental installations throughout the country at the present time. A number of schools recently installed systems on an experiemental basis with gratifying results. A school in Tamonium, Maryland installed a heating system on the roof

Solar Energy







Banks of solar collectors (1) sit on the roofs of four recently completed solar powered townhomes at New Century Town, Vernon Hills, Ill. Concentrating solar energy collectors (2) are shown on the roof of the University of Texas at Arlington "Discovery 76" test house. These solar collectors (3) are round glass tubes designed to convert sunlight into heat energy.

of one of its existing schools and it provided 91 percent of the heating needs during a 60-day period from March 11 to May 14, 1975. Another school in Minneapolis, Minnesota installed a system which provided 100 percent of the school's heating requirements in December from 11:00 a.m. to 4:00 p.m.

NO SUNLIGHT?

The solar system does have the capability of storing energy for a number of extended days. The exact duration depends on the size of the storage tank and the degree to which the hot water is originally heated. In any case, conventional backup systems are needed in case we have extended periods of sunless days and the conventional system must take over where the solar system cannot provide adequate heat for the building.

FIELD LOOKS BRIGHT

Even with the existing problems the field of solar energy looks bright. The solar system offers the ability to utilize a clean and efficient kind of energy always available to us and one that will not pollute the environment. With continued governmental support and experimentation the efficiency of solar systems will improve.

It is anticipated that the government will maintain a supportive role for solar energy and recently the Congress has been discussing tax credit and incentive programs for the owner to install a solar system.

Many of the existing problems that we face today might be resolved with the improvement of the solar collector. Experimentation is now being developed on what is known as tracking collectors that actually follow the sun in order to absorb the rays. Another collector now being developed is known as a concentrator collector. This means that the sun will be concentrated into a small area of the collector in order to produce higher water temperatures rather than over the entire surface of the flat plate collector that we are currently using.

CONCLUSION

The development of the solar system is well along the road. Significant gains have been made since the original energy crisis of 1973-1974 and the future promises to bring improved technology and lower costs so that many of us can install a system whereby the sun's radiation can be used. Many of our homes and buildings may not be able to receive in the future natural fuel sources because of our excessive demand and we may be forced to utilize a solar system to supplement these natural fuel sources. □

Solar Thermal Energy: Bringing the Pieces Together

Solar thermal systems can pump water for irrigation, produce steam for industrial processes, generate electricity in small and medium-sized installations, and also supply heat for residential use. Systems that operate at temperatures between 100° and 400°C are suitable for each of these purposes, and early studies indicate that they may be most economic when they serve several purposes in a complementary fashion. Although most attention and funding in the U.S. solar program has been devoted either to low-temperature systems for solar heating and cooling or to high-temperature systems for centralized generation of electricity, a number of analysts are beginning to believe that the greatest potential for solar energy utilization by 2000 lies with intermediate-temperature systems.

This is the fourth in a series of Research News articles examining recent developments in solar energy research.

One of the largest potential markets is in food, textile, and chemical industries where large amounts of intermediate-temperature heat are consumed. Thirty percent of all industrial process heat is used at temperatures below 300°C, and solar systems would be well matched to industrial purposes because the demand is nearly constant year-round. One study recently prepared for the Energy Research and Development Administration (ERDA) projected that by 2000 solar energy could displace 7.5 quadrillion Btu (quads) of fossil fuel now used for process heat below 300°C. Comparable projections are not available for solar irrigation, electrical generation, or combined heat and electricity production, which ERDA has named "total energy." But intermediate-temperature systems are capable of making a major contribution to all these areas because the hardware is varied enough that it can be easily tailored to different applications.

All the pieces needed for intermediate-temperature systems exist now. Development of concentrating solar collectors that can raise fluid temperatures above the boiling point of water has progressed particularly rapidly. At least ten varieties of one-axis tracking collectors are now being made in the United States, and the cost—before installation—is generally comparable to the cost of simpler flat-plate collectors used for space and water heating at 50° to 100°C.

The development of other components is less advanced, but nevertheless examples are available. In particular, the current designs for small heat engines (that convert solar heat into shaft power to drive a generator, air-conditioning compressor, or water pump) have been characterized as "archaic" because American engineering effort has been devoted to turbines for large-scale applications in recent decades. European firms are frequently ahead in this field. But a number of American firms are producing and selling prototypes, and one company is setting up a modest production line for solar heat engines later this year.

Prices Comparable to Flat-Plate Collectors

Although the pieces are available, very few institutions have put them together to build complete systems. In the United States there are now two irrigation systems, one total energy test-bed, about a half-dozen industrial process heat projects, and a larger number of solar air-conditioning systems that use tracking collectors. The cost of one-axis tracking collectors for such installations is now $50 to $200 per square meter, as compared to $500 to $1000 for the more elaborate two-axis tracking collectors planned for use in centralized electric generating systems. The wide range of costs is an indication of the diversity of designs and manufacturing techniques employed. "When the industry is just getting tooled up, you are bound to get that sort of spread," says one observer. Most companies project a cost below $100 per square meter in mass production. The potential for cost reductions in small heat engines is even greater. The custom-made heat engines used today cost about $1000 per kilowatt, but mass production techniques could reduce the figure to $200 or possibly even $20 per kilowatt, which is about the cost of automobile engines.

The federal research program for intermediate-temperature systems is fragmented. Work on improved heat engines is done in ERDA's conservation directorate. Funding for model total energy systems comes from the agency's solar thermal division—$9 million out of a $69 million effort to develop centralized solar electric stations (*Science*, 22 July). Support for industrial process heat comes from the ERDA solar heating and cooling branch. Photovoltaic cells can be used in total energy systems, but there is no organizational slot designated for such research. All the intermediate-temperature systems use collectors that concentrate sunlight by a factor of 10 to 60 and therefore draw on the same pool of solar technology. But the ERDA solar program is organized by electricity-production classifications rather than solar capabilities, so the various mid-temperature applications are separated from each other in a way that gives them very little visibility.

Solar-powered water pumping has been one of the first intermediate-temperature applications to get under way. The first and so far the largest solar pumping facility in the United States was built not by the government but by a private R & D laboratory with the backing of a large life insurance company. Northwestern Mutual Life had a farm near Phoenix, Arizona, that needed water and Battelle Memorial Institute wanted to build on its experience in solar energy research, so the two of them undertook a 50-horsepower (38-kilowatt) irrigation project in August 1975.

Within 18 months, the joint project began pumping water at Gila Bend, Arizona. The system has 550 square meters of collector surface and at the peak of solar insolation in June it can pump 10.6 million gallons of water per day. The collectors are parabolic troughs made of aluminized Mylar by the Hexcel Company and the heat engine is a Rankine cycle turbine developed by Battelle using Freon as a working fluid. The system efficiency is 7 to 9 percent, and the facility has been operating for 4 months with very little maintenance (including only one washing of the collectors).

As the first of its kind, the system cost about $250,000, but Frank Dawson at Battelle estimates that in limited production the cost would be $75,000. Battelle and Northwest Mutual have found that there are over 300,000 irrigation pumps in use in the western United States, operating at an energy cost over $700 million per year, and most of them have about the same power as the Gila Bend facility.

The operating temperature of the Battelle–Northwest Mutual system is 150°C, considerably higher than that attainable with flat-plate collectors. The thermodynamic advantage that intermediate temperature affords can be seen by comparison with a flat-plate solar irrigation system being sold by a French industrial consortium SOFRETES. The overall efficiency of the SOFRETES system is only 1 percent, so it is very expensive. Although the system is reportedly subsidized, a 1-kilowatt version costs about $15,000.

Battelle–Northwest Mutual is not the only American enterprise that thinks it can undercut the French price. An engineer who has been working on heat engine development since 1968 is selling 10-kilowatt solar irrigation systems for a package price of $40,000. Wallace Minto, who heads Kinetics Corporation in Sarasota, Florida, has sold three of these systems for use in Sri Lanka, Senegal, and Mexico.

The operating efficiencies of solar systems are particularly important because they determine how much solar collector area is needed for a given purpose, and collectors make up more than 50 percent of costs in a typical solar installation. The foremost merit of intermediate-temperature systems is that they can achieve markedly better efficiency than low-temperature, flat-plate systems with little or no price increase. The most complete facility for testing intermediate-temperature systems is the government's total energy test facility at Sandia Laboratories in Alburquerque, New Mexico. Researchers there are currently operating a 32-kilowatt system, that generates electricity and produces heat for use in one of the laboratory office buildings. It will be used to test several types of collectors and heat engines, as well as thermal storage systems.

Although planning for the total energy program is still evolving, ERDA envisions some rather large systems. Agency spokesmen doubt that the optimum system would produce less than 200 kilowatts of electricity, [illegible] the program plan includes a slot for a very large facility that would produce 10 megawatts of electricity plus concomitant heat. The proper balance between electricity and heat in a total energy system is also being studied in the ERDA program.

As the ERDA program moves toward larger total energy systems, the agency has already approved two $10-million projects that will be built at the end of this decade at Shenandoah, Georgia, and Fort Hood, Texas. Each of the projects will produce 200 kilowatts of electricity and 1.5 megawatts of thermal power. As such, they are the most ambitious projects undertaken to date in the intermediate-temperature field.

The Shenandoah project is particularly interesting because it will produce electricity, hot water, heating, cooling, and process steam for a textile factory employing 150 people. When the factory is completed in 1981, it will be leased to the West German knitwear firm of Wilhelm Bleyle, K.G. In direct sunlight the solar system will produce 1000 pounds of steam per hour at a temperature of 169°C—it is sized to supply all the heat the factory needs. The solar energy system will have 6,000 to 10,000 square meters of collectors when it begins operating in 1981, and there are plans to later double the size of both the solar energy system and the factory.

A Parsimonious Program

Apart from the total energy experiment, the ERDA program has been terribly parsimonious toward projects for producing industrial process heat with concentrating collectors, putting most of its money instead into agricultural projects using flat-plate or evacuated tube collectors. This preference is particularly hard to understand when the agency's own projections show that solar agricultural projects could displace 1 percent of the country's fuel usage in 2000, while solar industrial projects could displace 4 percent. Out of a total of 72 projects, the ERDA agriculture and industrial process heat program has only three projects that use concentrating trough collectors. One will provide 85°C water for washing cans at a Campbell Soup Company plant in Sacramento, another will produce 157°C steam for fabric drying at a plant in Alabama, and the third will produce some of the hot water needed at a Pennsylvania concrete-block plant. Construction of the three is due to begin this summer.

While the government is moving slowly with a few projects, the private sector is moving more quickly to commercialize intermediate-temperature solar technology. For relatively low temperatures (100°C), the Albuquerque-Western company already has a tracking parabolic trough on the market for $50 per square meter. A more highly concentrating parabolic trough being sold by the Acurex Corporation can reach 311°C for factory price of $160 to $240 per square meter. An alternative approach is to build a fixed trough made of strip mirrors and collect sunlight throughout the day by moving the receiver. The firm of Scientific-Atlanta is marketing such a concentrator, designed to reach 316°C, for about $150 per square meter. The design was developed by General Atomic, which is testing and selling research versions that can reach 497°C. A different strip-mirror collector being developed by Sheldahl for testing in the Sandia total energy facility costs about $250 per square meter. Most of these devices will deliver over 50 percent of the sun's energy to the heat-transfer medium in the collector.

While the preceding collectors all focus sunlight into a line through reflecting mirrors, a small company in Texas has marketed a steerable trough collector that achieves the same effect using a Fresnel lens. The collector produces heat at 120°C with 65 percent efficiency. Northrup, Inc., a heating and cooling company that developed the unit with $250,000 of its own money, now has orders for over 10,000 square meters of collectors, and is working on an advanced unit to produce higher temperatures.

To the factory price of a tracking collector, auxiliary equipment costs, middleman profit, and installation costs must be added. These factors multiply the basic cost by a factor of 2 to 4. Although the price of tracking collectors is limited to a considerable extent by material costs, observers of the industry think that substantial reductions can be achieved by clever design and improved manufacturing techniques.

The heat engines needed in many intermediate-temperature systems have been ordered one at a time—usually handcrafted by research and development companies at very high prices. Battelle reports that the engine for its irrigation project (a Rankine cycle turbine using Freon as the working fluid) cost $50,000, but if it were mass-produced the same engine should cost no more than $3000. The Office of Technology Assessment notes that if 10,000 small turbines were produced each year, the cost should fall to $200 to $300 per kilowatt, and Jet Propulsion Laboratory estimates that units produced on the scale of auto engines should go for $13 per kilowatt. Wallace Minto is reportedly setting up a facility to produce 10-kilowatt Freon heat engines at the rate of 100 per month, and his company is selling the entire packaged with an alternator for $1250 per kilowatt.

Because of the wide range of technology already available, intermediate-temperature solar energy systems offer great flexibility to perform many jobs through rapid deployment at small scales. Much opportunity remains for innovation—a challenge only one step up from the sort of backyard inventorship at which Americans have often excelled.

In the early 1970's, the surprising truism of solar energy was that residential systems were ready for use. The largely unappreciated truism of the late 1970's is that the key components of industrial and commercial systems are now ready for wider use.—WILLIAM D. METZ

Energy from the sea...

Part II: Tapping the reservoir of solar heat

The largest solar collector in the world is one that cost us absolutely nothing to build—the surface waters of the oceans

By ARTHUR FISHER

The overcast thinned, the sun peeped through, and suddenly the little red toy propeller in Dr. Robert Cohen's Washington, D.C., office was whirling faster. It was driven by a miniature motor powered by a flat solar cell, the whole neat package sitting flush against the inside of his window.

"I'd like to see one of these little demonstration models in the window of every decision-maker in this town, just to remind them about solar energy," Dr. Cohen told me.

Odd words, you might think, from the man who is heading one of the nation's programs to extract energy from the sea. But it's perfectly logical. Bob Cohen is program manager for Ocean Thermal Energy Conversion, under the Division of Solar Energy of ERDA—the new federal Energy Research and Development Administration (he held the same job at the National Science Foundation when I first spoke to him).

The link between sun and sea is obvious, although its implications may not be. "To the layman," says Dr. Cohen, "energy from the sea means tides. But there's a larger, less conspicuous resource. Much of the energy the sun provides us is absorbed by the oceans—a naturally existing thermal collector and storage device that smooths out the intermittence. Unlike tides, waves, and winds, the heat stored in the sea is available on a continuous, steady basis day and night, year in, year out. And it is a tremendous amount of energy—enough to run the whole country . . . the world, for the foreseeable future."

Indeed, many of the scientists I spoke to in preparing this series of articles on energy from the sea are equally impressed. They strongly believe that energy converted from ocean thermal differences—renewable, essentially nonpolluting, and requiring no complex new technology—could begin to make a significant contribution to our energy needs in the 1980's. Eventually, many of them hope it could help supplant what they consider to be an undesirable and potentially dangerous source—nuclear fission.

(For a comparison of the various ocean energy sources on the basis of their size and energy density, see part I of this series, "Energy from the sea . . . waves, tides, and currents," in last month's PS.)

The oceans' thermal resource is as enormous as it is because of the way the distribution of water on the earth's surface neatly dovetails with the solar system's geometry. It turns out that about 50 percent of the torrent of solar energy intercepted by the earth falls between the Tropic of Cancer and the Tropic of Capricorn. And in this sweltering region, 90 percent of the surface is covered by the sea. Therefore, a sizzling 45 percent of all of earth's incoming solar energy is absorbed by the tropical oceans.

The result is that the surface temperature of these waters is very high, ranging from about 70° F to about 85° F (roughly 21° C to 30° C), as any vacationer in these balmy climes can attest. This tepid layer is often 300-600 feet thick.

Continued

Huge, 400-megawatt ocean-thermal-difference generator is a concept developed by the Energy Research Team of University of Massachusetts. Dubbed the Mark II Model Two System, it would be tethered in the Gulf Stream by a single-point mooring, and would ride there like an underwater kite. Concept uses a heat cycle called the closed Rankine cycle, in which temperature difference between warm surface water and cold subsurface water is used to vaporize and condense a working fluid that drives a turbine. In the drawing, cold water is sucked from about 75 feet above sea floor through inlet pipe (1), through inlet doors (2) into condensers (3) inside the twin 85-foot-diameter hulls, and is discharged through outlets in walls of the hulls, with suction maintained by the circulating cold-water pumps (4). At the surface, warm water is sucked through pod-mounted evaporators (5) by warm-water-circulating pumps (6). Ballast tanks (7) maintain negative buoyancy so entire unit floats just below ocean surface.

Working fluid, either propane or ammonia, flows from reservoir (8) to evaporator feed pump (9), which pressurizes it, through evaporator (5) where it is boiled into a vapor by warm seawater. The vapor passes through a turbine (10), which spins its generator (11). The vapor expands through the turbine exhaust diffuser (12) and then passes through the condensers (3) where it is condensed by cold seawater. The liquid returns to the reservoir (8) to complete the cycle. Each hull, pressurized at one atmosphere, contains eight power packages consisting of a condenser, turbine, and generator. Each power package generates 25 Mw net electrical power.

ILLUSTRATION BY RAY PIOCH

Converting ocean thermal differences into electricity is simple. The

This vast reservoir of warm water (enough, by some calculations, to supply 10,000 times the world's energy needs) would be useless for energy generation unless there were also available a colder body to which the stored heat could flow. It is a fundamental law of physics that if heat energy is to be converted into work, either mechanical energy or electricity, there must be a temperature difference between two heat reservoirs—one a high-temperature heat source, the other a low-temperature heat sink. Without the heat sink, the heat in the high-temperature source could do nothing. The hot steam in a steam engine does work only because it is hotter than the cooling water that condenses it.

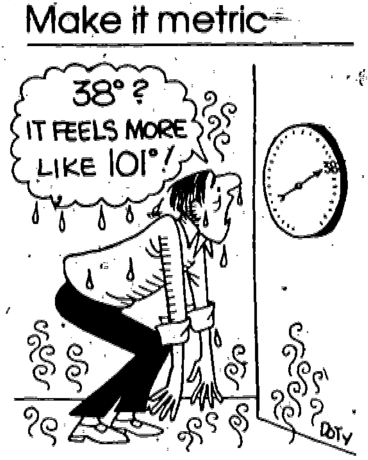
Cold underneath

Fortunately, there exists just such a heat sink in the oceans. It is the vast body of cold sea water underlying the warm surface water. In the deeps, perhaps as little as 1500 or 2000 feet below the surface in some places, the waters are a dense and frigid 35-38° F. Except in a few spots, where there is cold-water upwelling, the hot and cold layers do not mix. Instead, separated by their different densities, they go through a slow and elephantine dance, a global circulation pattern that sees the warm surface waters flow from the equatorial regions to the poles where they are chilled and sink, just as the deep, cold waters slide clammily under them toward the tropics, there to be warmed and made buoyant. Fueled by the sun, and directed by the earth's rotation, this eternal pattern ensures the existence of two great reservoirs of water with a considerable thermal gradient, or temperature difference, between them. Theoretically, this difference could be used to run a heat engine that could in turn drive a generator that is capable of producing electricity.

In 1881, a remarkable French physicist named Jacques d'Arsonval made the prescient suggestion that in future, man might use the thermal gradients in the sea to produce electric power, instead of burning fossil fuels. (He also invented the kind of moving coil galvanometer that now bears his name.) The problem was—and is—something called the Carnot efficiency of heat cycles. Nicolas Carnot, born in 1796, lived a brief (36-year) life in which he founded the new science of thermodynamics. From his work stemmed one of the most important of all rules governing the transformation of heat to work, either mechanical or other forms of energy. The maximum efficiency of a heat cycle is $(T_1-T_2)/T_1$, where T_1 is the temperature of the hot source and T_2 the temperature of the cold source, with temperatures expressed as degrees Kelvin. (Add 273° to the temperature in degrees C to get these values.)

From this important rule, it follows that the greater the spread in temperature between the heat source and the heat sink, the greater the efficiency of the energy conversion scheme and the lower the fuel cost. As a result, power-plant engineers have striven to boost this temperature gradient as much as is practical. Modern coal- and oil-fired plants conventionally operate with a differential of about 500° C, and other schemes call for temperature differences in the thousands of degrees. For conventional plants, the net operating efficiency is somewhere around 30 percent.

Make it metric



To convert degrees C to degrees F, multiply degrees C by 9/5 and add 32 degrees.

But if you calculate the usable temperature gradient in the oceans at, say 20° C, you wind up with a maximum Carnot efficiency of about 6.7 percent.

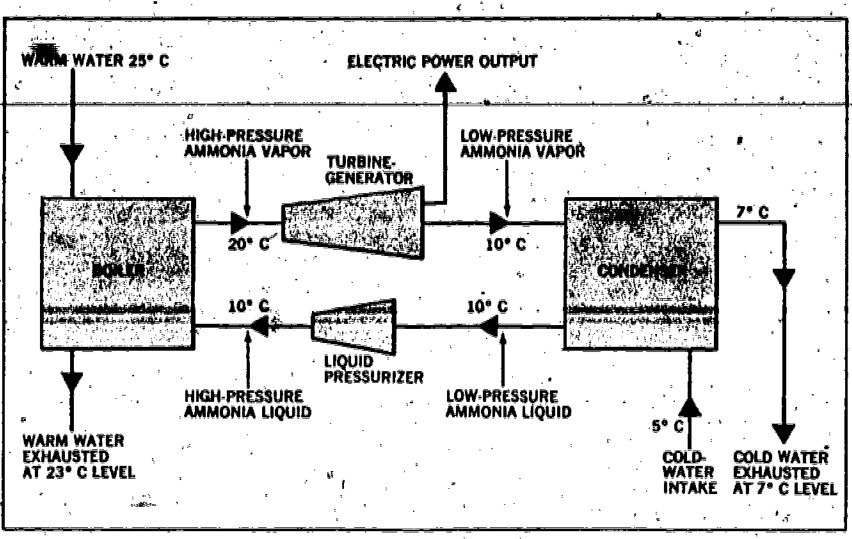
Since the fuel—the hot and cold water—is free, you might ask what difference the very low efficiency makes. The answer is that to extract reasonable quantities of *power*—the time rate of energy production—enormous quantities of water must be rapidly circulated past vast areas of heat exchangers, and deep cold water must be brought near the surface. That poses problems that add to the capital cost of building such a power plant. Is the effort worth it?

A Frenchman named Georges Claude decided it was in the late 1920's and the 30's. He built a plant, based on the shore at Matanzas Bay in Cuba, and ran his cold-water inlet through the surf. Claude managed to get 22 kilowatts out of his installation, but whether that was a *net* output—whether the plant was really delivering more power than was put into it—is still unclear. At any rate, the plant was not an economic success, and the problem of maintaining the cold-water pipe through tropical storms was insurmountable.

One of Claude's problems was his choice of one of two possible heat cycles to drive his plant. He opted for the open cycle, which uses seawater as a working fluid as well as a heat source. It works this way: The warm surface water is flash-evaporated into steam inside a boiler where a partial vacuum is maintained—around a half pound per-square-inch pressure for water at about 70° F. (At atmospheric pressure, roughly 15 psi, water won't turn to steam unless it's heated to 212° F.) The steam then flows through a turbine, which spins a generator, and electric power can be taken off.

Open-cycle advocates

Claude's successors did not have much luck with another open-cycle scheme off the Ivory Coast of Africa in the 1950's. And there are still persuasive advocates of the open-cycle system working today. They include Dr. Donald Othmer, Distinguished Professor of Electrical Engineering at the Polytechnic Institute in New York, and Dr. Oswald A. Roels of Lamont-Doherty Geological Observatory. Both men have been active in promoting open-cycle, shore-based plants in the Caribbean. In such plants, the deep cold water brought up contains concentrated nutrients that are valuable for mariculture, the cultivating of seafood such as shrimp and oysters in "pens" filled with the deep water sucked up for the power plant. (An experimental installation on St. Croix in the Virgin Islands has apparently demonstrated the practicality of such a mariculture scheme. See PS, March '71.) A bonus from such open-cycle plants is fresh water from the condensate, a salable commodity.



Closed Rankine cycle for solar sea power plants such as the Heronemus concept on page 79 is shown here schematically, with data supplied by Clarence Zener and Abrahim Lavi of Carnegie-Mellon University. Note that although temperature difference between warm and cold sea water is 20° C, only half this gradient is actually available to the heat engine itself. The other half is needed to drive heat from the warm surface water into the evaporator and from the condenser into cold deep water. The gross efficiency of such a heat cycle is about 3.3 percent; the net efficiency, after accounting for pumping and other losses, is about 2.2 percent.

But the open-cycle system has severe handicaps when it comes to generating power alone. Steam at the water temperatures available has such a low vapor pressure that it requires a very large diameter turbine to produce significant quantities of power, so large that the capital cost for building such a plant might well make the whole scheme uneconomical, in the opinion of at least some power engineers.

And, as one engineer told me, "We don't want to kill the goose that lays the golden egg. Is the golden egg shrimp, or is it power? I vote for power."

So does Dr. Cohen, late of the National Science Foundation and now at ERDA. "It looks as though the consensus is, that if you want ocean thermal power, the closed Rankine cycle is the way to go." And that's why, in part, the government, via the NSF, has awarded funds for research in ocean thermal work to scientists and engineers closely associated with the closed-cycle approach. The principal ones are J. Hilbert Anderson and his son James Jr., of Sea Solar Power, Inc. in York, Pa.; Dr. Clarence Zener and Dr. Abrahim Lavi, of Carnegie-Mellon University in Pittsburgh, Pa.; and William E. Heronemus, Professor of Civil Engineering at the University of Massachusetts, Amherst, Mass. Their proposed ocean thermal-difference devices differ in many details, but they all use essentially the same thermodynamic cycle.

Applying the Rankine cycle

The closed Rankine cycle resembles a refrigeration cycle. A working fluid that boils with a high vapor pressure at a convenient (for the oceans) temperature circulates endlessly inside the heat engine, in a closed loop continuously changing from liquid to vapor phase and back, never (accidents excepted) escaping. This liquid is compressed first, then flows into the boiler or evaporator on one side of a heat-exchange surface. Warm water flows into the boiler on the other side of the heat exchanger and gives up enough heat to vaporize the working fluid. This high-pressure gas then enters the turbine and expands, doing work by driving the turbine, which can be connected to an electrical generator. The gas, now at low pressure, enters a condenser, where it surrenders heat, through another heat-exchange surface, to cold water from the depths.

The working fluid could be ammonia, propane, or one of the Freon-like fluorocarbons; each has its merits, and its proponents. Because the vapor pressures of these fluids are so much larger than seawater under a vacuum, the turbine size can be reduced to practical dimensions. The efficiency of such devices, however, is theoretically lower than open-cycle systems, because considerably less of the thermal gradient is available to the heat engine itself. (See schematic, page 81). The *net* efficiency of a closed-cycle system is about 2.2 percent. "The thinking now," says Dr. Cohen, "is to place such plants at sea, not on shore, to obtain the greatest energy potential. The amount of energy you can get when you site the plant on shore is limited. First of all, coastal land is very expensive. And the slope of the beach as it runs out to sea has to be very steep; otherwise you wind up running miles and miles of pipe to get your cold water. And of course you've got to have a good thermal resource. There aren't too many places where all these things are favorably combined. . . . Our goal is to generate very substantial amounts of electricity, so we think we have to go to floating plants at sea."

One proposal for such a plant, developed for Dr. Cohen's program, is pictured on the opening pages of this article. Professor Heronemus designed the mammoth device to provide 400 megawatts of power, a scale many experts in the ocean-thermal field consider to be a more or less optimum size. (One hundred megawatts would supply the residential electrical needs of a city of 300,000 to 400,000 persons.)

"Our system," Prof. Heronemus told me, "is based on an idea of J. Hilbert Anderson and his son. They said that even though the United States doesn't have any tropical waters, it has the warm Gulf Stream. We want to let the Gulf Stream deliver the warm-water resource to the device, and then we grab hold of it and pump it through the evaporators. We want to moor it about 15 miles offshore from the University of Miami for the first site. Mooring is going to be a problem, but it's feasible. And we'll use either propane or ammonia. Ammonia has better thermodynamic properties, but propane is much easier to handle. . . . The condensers in this concept look a lot like big automobile radiators—they're plate fin heat exchangers, but the plates stand about 30 feet tall, and the cold water flows across the plates through one-half-inch-wide passageways.

Ready in six years

"We could have the first of these 400-megawatt plants on station, generating electricity at a reasonable price, at the end of six years, with a program that would cost the government $540 million. I've participated in such programs—the Polaris project was bigger—and I know it's feasible."

J. Hilbert Anderson, whom Prof. Heronemus (and others) cited as a source of inspiration, was in turn taken by the ideas of Georges Claude. Mr. Anderson (Sr.) told me that when he first became interested in ocean thermal differences, in 1962, he had had long experience with gases, turbines, and air conditioning and refrigeration equipment (he was a chief engineer for the Borg-Warner Corp).

Under an NSF grant, the Andersons have designed a small, working model of what they call a Sea Solar Power Plant. The model puts out 100 watts—enough to light a bulb—when energized by two tanks of water, one warm, one cold. Mr. Anderson was pleased to note that the turbine of this demonstration model turned over when the temperature differential was as little as 3° F, using a refrigerant called R-11 as the working fluid.

Of course, Mr. Anderson has bigger things in mind. To wit: a 100-Mw plant the size of a ship, about 400 feet long, with the deck 10 feet above the surface where the warm-water intake is.

My last port of call on ocean thermal differences was at Carnegie-Mellon University, where I talked with Dr. Abrahim Lavi, Professor of Electrical Engineering, and University Professor Dr. Clarence Zener. (Yes, the same physicist who developed the Zener diode way back in 1934, "a whole lifetime ago," he says. And Bob Cohen says, "I twit him by saying he's switched from solid state to liquid state.")

The Zener-Lavi Carnegie-Mellon team has been concentrating mostly on developing engineering systems analyses, and on ways to improve the performance of heat exchangers.

Says Dr. Zener: "We think that power can indeed be obtained via the ocean thermal-differences route at a sufficiently low cost to make a very significant impact on our energy needs. This is a low-technology field—it doesn't require any major technical breakthroughs."

Dr. Lavi: "If we were to shift gears right now, we could have a one-megawatt ocean-thermal plant working in two years, off an island like Hawaii, with an expenditure of just $20 million—a test facility. . . . We could begin to get commercial-size, 100-200-Mw plants on line in the 1980's. We could build a dozen of them a year."

Some scientists have expressed concern over the possible ecological impact of such power plants. Dr. Zener comments thus: "I asked the question, by what amount would we have to reduce the rate of evaporation in the tropics to supply all the energy now being used in the world? And the answer is three percent. I don't know whether the tropical countries would complain about being a little less wet and a little cooler."

Dr. Cohen has recently let a contract to the Naval Research Laboratory to look at the environmental impact of "moving water around at millions of gallons a minute."

What lies ahead

As of this writing, ERDA is preparing a comprehensive long-term energy program to submit to the Congress, perhaps this month. But Dr. Cohen says, "We're still shooting for a floating pilot plant, maybe 25 megawatts, in 1981. That would be a rather nice coincidence—the centenary of d'Arsonval's original paper . . . he recommended the closed cycle, by the way." And informed sources in the field believe that the government will field a 100-megawatt commercial demonstration model by 1985.

There are still, even in this "low-technology" field, many problems to be solved: fouling of the heat exchangers by marine organisms; mooring vs. dynamic positioning; which working fluid to use; corrosion of the metal parts; many other details. But the problems seem to be solvable with a reasonable application of money and man-hours. Two independent studies on ocean thermal power (by teams headed by Lockheed and TRW) should be made public this month.

What will happen after that? I will quote, without comment, Professor Heronemus on the subject: "The largest problem confronting energy alternatives is a public-relations problem. The only way we're going to get these alternatives, such as ocean thermal-differences generators, is for enough ordinary citizens to decide that they want them." ■

POWER FROM THE SEA

BY MARK SWANN

Twenty-four hours a day

ONE OF THE most tantalizing potential energy sources in the world today is relatively unknown to the general public — it is *sea thermal power*, a method of producing energy by using heat engines to harness the small temperature variations between the sun-heated surface of the tropical seas and the cold deep water.

Sea thermal power is by far the ocean's greatest renewable energy source, being replenished daily by solar radiation. One team of researchers has estimated that this power source is capable of providing, on a continuous basis, 200 times the earth's total power needs in the year 2000.[1]

There is one great difference between sea thermal power and other solar energy technologies: Because the surface of the tropical seas never falls below 78 degrees F. at any time, it will be possible to operate sea thermal power plants at full output, or close to it, for 24 hours a day year-round. That is, since the ocean's surface waters act as a vast repository of solar heat, sea thermal plants will not require heat storage capacity in order to produce power during periods of little or no sunlight. Down time (when plants are not in operation) will therefore be limited to periods when major repairs and maintenance must be undertaken.

All other proposed systems for use of the sun's energy (with the exception of arrays of solar cells orbiting in space beyond the earth's shadow and outside its atmosphere) require some means of storing heat or electricity. Such a constraint increases plant costs in two ways: First, the solar collectors themselves must be several times as large in such systems as in a system which requires no storage. Solar collectors in the Arizona desert, for example, receive useful solar heat for about 8 hours a day. If such a system is to provide energy for 24 hours a day, it must have three times as much power capacity as one which operates continuously day and night. Second, if a highly efficient storage and retrieval system is used, it is very expensive. In a small windmill power system, for example, the cost of the battery storage component is usually 50 percent of the total cost. In a large power system, a cheaper, less efficient (about 50 percent) storage system would probably be used. The power capacity of such a system would have to be further increased, in order to supply the additional power lost in

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Since the ocean's surface waters act as a vast repository of solar heat, sea thermal plants will not require heat storage capacity in order to produce power during periods of little or no sunlight.

retrieval. Limits on available amounts of sunlight constitute probably the most important obstacle to widespread solar development. (Of course, if a solar power system is intended for peak power demands only, which usually occur during daylight hours, storage is not necessary.)

How It Works

The heat engines in sea thermal plants transform heat energy into the mechanical work of spinning a turbine. Heat engines in fossil-fueled and nuclear power plants perform the same operation. In both cases, generators are connected to the turbines to produce electricity.

The main consideration here is the step involving transformation of heat energy into mechanical energy to drive the turbine. According to the second law of thermodynamics, heat can be transformed into work only while it flows from a hotter "heat source" to a colder "heat sink." In a steam turbine powered by oil or coal, fuel is burned to provide heat, and the natural outside environment is the heat sink. The burning fuel heats the water in the boiler, producing steam (the working fluid), which expands and is driven by the rush of heat to the heat sink. The turbine, a special kind of wheel, or series of wheels, with vanes or buckets mounted on it, harnesses the rushing steam. Some of the steam condenses into water as it gives up energy in the turbine. Remaining steam is condensed in the heat sink, also called the condenser (see Figure 1).

This entire process is what is meant by harnessing the *variation* between two temperatures. The application of this principle to the ocean's stored heat was first suggested in 1881 by Jacques d'Arsonval. One of his students, Georges Claude, went on to build a small working sea thermal plant on the coast of Cuba in the late 1920s.[2]

While steam is the working fluid in a steam turbine, Claude used warm sea water as the working fluid in his sea thermal plant, a method now referred to as the Claude process, or the open cycle method. The problem with the Claude process, however, is that the air pressure on the warm water must be lowered to a point where vapor will form which can propel a turbine. Water vapor, however, has a low density which requires that the turbine have a proportionately large area of vanes. Such a turbine for a commercial plant would be inordinately large, expensive, and difficult to maintain. An open cycle turbine for a 100-megawatt sea thermal plant, for instance, would have to be more than 40 feet in diameter.

An alternative to warm water would be a type of working fluid which vaporizes (boils) at the upper reaches of the given temperature range, yielding a high-density vapor, and, of course, condenses in the lower end of the range (as in an ordinary refrigerator). Warm

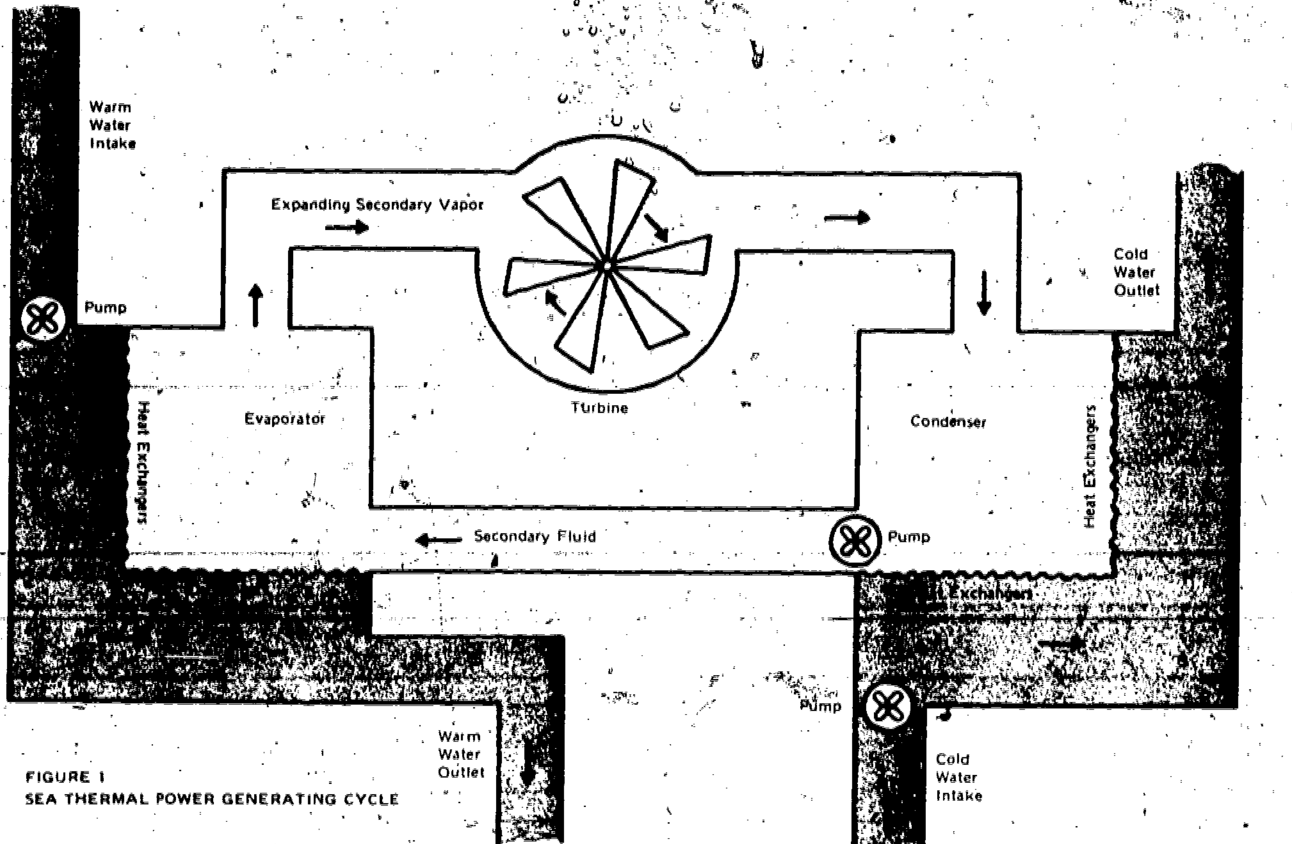


FIGURE 1
SEA THERMAL POWER GENERATING CYCLE

and cold sea water would then be used alternately to vaporize and condense the working fluid. Turbines for the working fluids — of which ammonia and propane are two possibilities — can be approximately one-tenth the size of an open cycle turbine.

"The use of a working fluid other than vaporized sea water, however, presents its own problem: Heat exchangers must be built into the plant design. A heat exchanger is simply a surface — usually metal — which separates the working fluid from the heat source and the heat sink, permitting the heat to travel from the source (in this case, warm sea water) through the working fluid (a more volatile fluid) and into the heat sink (cold sea water). There are many technical difficulties associated with the design of efficient heat exchangers for sea thermal plants. These will be discussed later in connection with plant construction costs.

Finding Warmer Waters

The general location of the sea thermal resource is, roughly, the 1,700-mile-wide area around the equator between the Tropic of Capricorn and the Tropic of Cancer. The ocean covers 90 percent of the earth's surface in this equatorial region. Some of the most promising areas for sea thermal development are the South Atlantic Equatorial Current area, the Gulf of Panama, Micronesia, and the northwest coast of Australia south of Java.[3] Other areas with usable temperature variations are the sea around Hawaii, most of the Caribbean, the Gulf Stream off the east coast of Florida, the Gulf of Mexico, the Arabian Sea, the Indian Ocean, the East Indies, and the Atlantic Ocean of the coast of West Africa.

One of water's most important properties in this application is that it forms relatively stable isothermal layers — layers determined by temperature and density — which can be tapped for sea thermal power without significant disturbance. The combination of this property with the global pattern of ocean circulation forms the physical and environmental foundation for sea thermal power. In general, warm water flows away from the equatorial regions while cold water from the polar regions flows under it toward the equator. In the Gulf Stream off the east coast of Florida, for example, warm sea water flows northward in a current more than 100 feet deep at a rate of 27 million tons per second with cold water flowing southward just beneath it. As the cold water reaches equatorial regions, it is heated, its density decreases, and it rises to the surface to begin its flow toward one of the poles. The reverse process takes place with warm water reaching the polar regions. This vast ocean circulation guarantees the renewability and reliability of sea thermal power's heat sink.

Cost Factors

While nuclear and fossil-fueled plants operate with artificially induced temperature variations of hundreds of degrees, sea thermal plants must operate on small, naturally occurring temperature variations (30 to 40 degrees F.). A fundamental law of thermodynamics is that, given a heat source and a heat sink, there is a maximum theoretical amount of useful work output. With a large temperature variation, the maximum theoretical amount is close to 90 percent; with a smaller variation, it is less than 10 percent. However, the *actual* amount of useful output is approximately half of the theoretical amount. Hence, a sea thermal plant will only yield about 2 to 4 percent efficiency in actual operation, while nuclear and fossil-fueled plants yield 30 to 40 percent. For many years, this extremely low efficiency discouraged many investigators of sea thermal prospects. What these investigators perhaps failed to consider is the total economics of the power source; if the fuel is free, the efficiency factor changes significantly.

With the costs of all conventional fuels continuing to escalate since the 1973 Arab embargo of crude oil, alternative energy sources have been more closely examined than ever before. Two years ago, the National Science Foundation (NSF) and the Energy Research and Development Administration (ERDA) awarded large grants for parallel feasibility studies of sea thermal power to two aerospace companies, TRW, Inc., and Lockheed Missiles and Space Company, Inc. These studies resulted in cautious corroboration of the conclusions of earlier pioneering studies: Sea thermal power is technically feasible and commercially promising.

The TRW feasibility report included close examination of the cost estimates of three different sea thermal research groups. One of the report's major conclusions was:[3]

The heat engines in sea thermal plants transform heat energy into the mechanical work of spinning a turbine.

"The TRW team has conservatively estimated capital costs of proponents' concepts, based on present technology in equipment, materials, and fabrication. A range, in 1974 dollars, between $1,400 per kilowatt and $1,700 per kilowatt spans the proponents' concepts. These figures are higher than proponents' estimates, all of which appear to *reflect significant economies resulting from technology development*. If the TRW estimates are regarded as reflecting present technology, the proponents' estimates would seem to give incentive to OTEC [ocean thermal energy conversion] technology development."

By comparison, estimated construction costs of nuclear plants planned for 1985 operation will range between $830 and $1,000 per kilowatt. Coal-fired plants, including devices to reduce emissions of sulfur dioxide and particulates, will cost about $750 per kilowatt to build. Both must buy fuel. Electricity from these nuclear plants will cost at least 37 mills per kilowatt-hour; electricity from the coal-fired plants will cost about 44 mills. Electricity from the sea thermal power plants may be as low as 25 mills per kilowatt-hour.

ERDA's position, based on the TRW and Lockheed studies, is that sea thermal power will be commercially attractive if the predicted capital costs can be cut from the estimated $1,400-to-$1,700 per kilowatt to about $1,000 per kilowatt. Research teams at the Johns Hopkins Applied Physics Laboratory, the University of Massachusetts, and Carnegie-Mellon University all believe the $1,000 figure is achievable.

Clarence Zener, professor of engineering at Carnegie-Mellon University and a leader of the sea thermal team there, believes that the cost of one of the most expensive items in a sea thermal plant, the heat exchangers, might be cut in half if specially designed surfaces to improve heat transfer were used — an improvement which would make possible the use of heat exchangers with a smaller surface area. While some experts estimate the exchangers to constitute 26 percent of the total cost of sea thermal plants, others estimate the cost at more than 50 percent. Thus, a significant cut in the cost of the heat exchangers could greatly reduce the construction cost of the entire plant. Most researchers agree that the development of low-temperature heat exchangers, a relatively new field, presents the greatest challenge in the field of sea thermal power.

Unlike conventional heat exchangers, sea thermal exchangers must handle enormous quantities of water—about 13,000,000 gallons per minute in a 100-megawatt plant. The area of the exchangers must be correspondingly large, running into millions of square feet. Since the available temperature variation is small, the efficiency of heat transfer must be high. While the heat exchangers in sea thermal plants are not required to withstand the high temperatures characteristic of nuclear and fossil-fueled plants, they must be able to resist corrosion by sea water. Fouling by marine organisms (slime and barnacles) could also be a very serious problem. Mechanical or chemical cleaning may be too expensive, as well as possibly harmful to marine life in the surrounding water. The choice of materials and design for heat exchangers must take all of these problems into consideration.

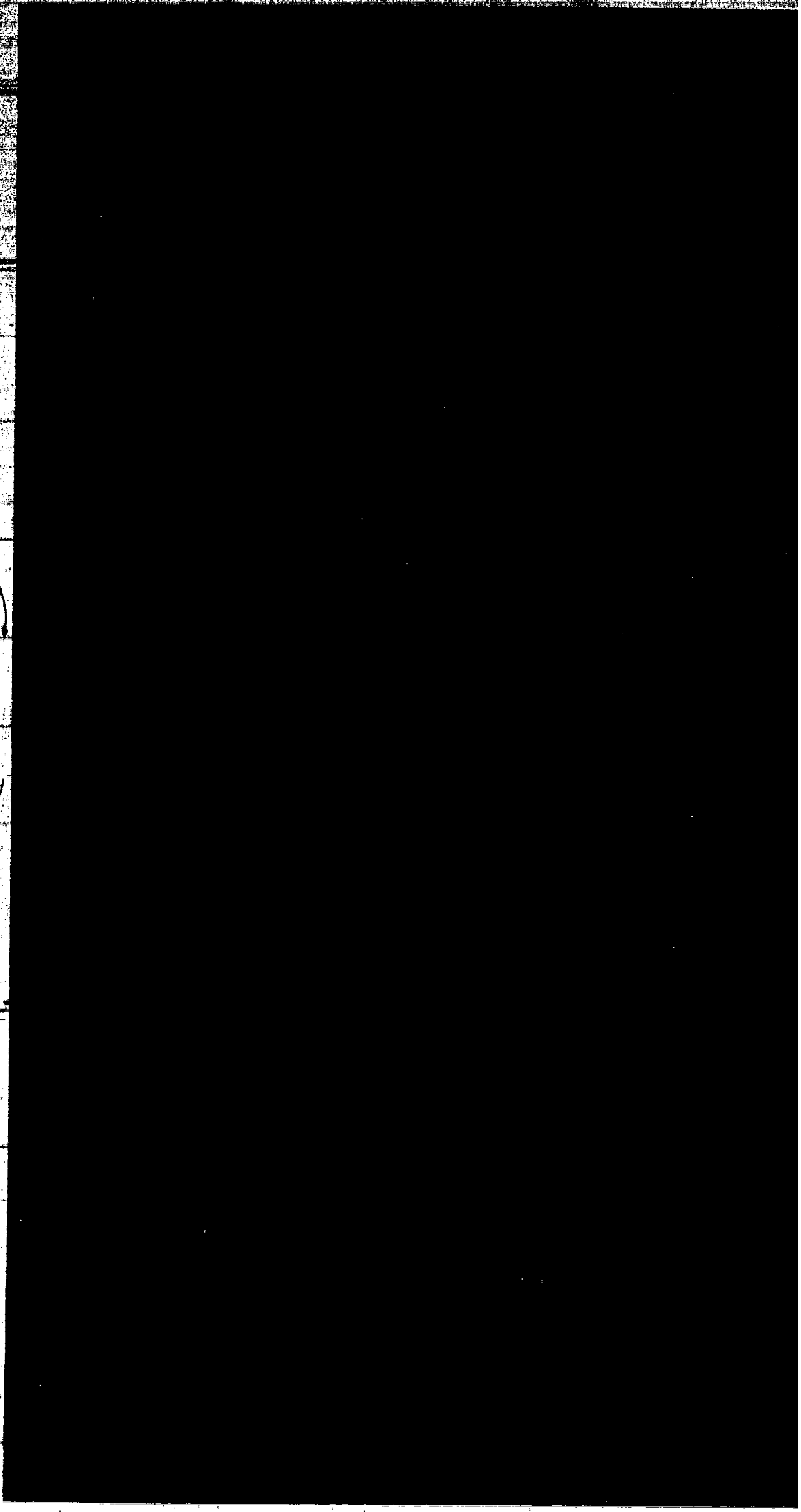
Yet another consideration is the differing characteristics of sea water in different locations. According to a privately funded feasibility study, performed for Sea Solar Power, Incorporated:[4] "Site selection is extremely important to the generation of trouble-free power.... The ideal site should have a gentle, directional current and an absence of fouling organisms and corrosive elements in the sea water."

The longevity of the plants and the reliability of power generation are two more aspects of the costs. Other specific economic factors will be discussed later.

Going to Sea

Most of the construction of sea thermal plants will be done in shipyards. Tugboats will move the plants to their sites. Cold-water pipes could be floated to the sites in telescoped form, as has been proposed by Lockheed, to be installed and extended there, or hauled to the site in sections for on-the-spot assembly.

According to a member of the TRW research team:[5]



Sea Solar Power, Inc.

Electricity from nuclear plants will cost at least 37 mills per kilowatt-hour, from coal-fired plants, about 44 mills, and from sea thermal power plants, possibly as low as 25 mills.

J. Hilbert Anderson, cofounder of Sea Solar Power, Inc., displays a model demonstrating the principle of a sea thermal power plant.

"In contrast with land-sited power plants, the opportunities for cost savings through replication are significant. An analogy, in terms of design and construction, is shipbuilding: Identical OTEC plants might be constructed in quantities constrained only by demand and production capacity."

Zener pointed out some years ago that the principles at work in sea thermal power do not involve advanced technology but, rather, "sophisticated plumbing."[6] A large part of the escalation of capital costs of nuclear plants has been laid to increasingly stringent safety and environmental standards. Sea thermal power, because of its intrinsic safety and ecological acceptability, will not be similarly affected.

The job of stationing a sea thermal plant on site involves problems of ocean engineering. The greatest challenge here is probably presented by the cold-water pipe, which must have a very large diameter (at least 40 feet) in order to decrease expensive pumping requirements. The pipe must be from 1,000 feet to 4,000 feet in length, depending on the site, in order to obtain the coldest water possible. With the small temperature range involved, each degree of temperature difference is crucial; questions of economy, such as whether it is worthwhile to lengthen the pipe to obtain water which is one degree colder, will have to be decided on the basis of further research and experience.

Several types of cold-water pipe have been proposed: concrete pipe resting on the ocean floor, telescoped concrete sections with voids for buoyancy, welded reinforced aluminum, steel pipe with inner walls of smaller-diameter pipe, and reinforced synthetic pipes. Research is now being done to determine the static and dynamic loads on these various pipes.

Fiber-reinforced plastic, or nylon coated with neoprene and stiffened with steel rods, appear to be promising materials for the cold-water pipe. It is not clear at this point whether the technology has advanced far enough to enable such pipe to be constructed economically.

The size and construction of the plant's hull are also significant factors in determining cost and siting. TRW's and Lockheed's baseline concepts call for very large cylindrical and spar hulls of reinforced concrete which will house the turbines, the pumps, and the heat exchangers.

J. Hilbert Anderson and his son, James H. Anderson, two pioneers in the field and founders of Sea Solar Power, Incorporated, believe that a much more compact hull is possible if the heat exchangers are placed outside the hull at depths where the ocean's hydrostatic pressure equals the pressure inside the exchangers. If the Andersons' proposal is feasible, not only can the hull be significantly smaller, but the heat exchangers can have thinner walls (because they do not have to withstand internal pressure) and can therefore be less expensive.

Positioning the plants will probably be done with the use of jet streams of used warm water and cold water from the plants, another innovation first proposed by the Andersons. Permanently mooring the plants appears expensive and unnecessary.

The most formidable ocean condition is the "sea-air interface," where waves, winds, and storms can do much damage. The best strategy is simply to submerge a large portion of the plant to depths where the water is free of wave action. The resulting stability will be much greater than, for example, that of off-shore oil rigs. Maintenance, of course, is made more difficult, but most of the plant should be relatively maintenance-free. The periodic use of frogmen, if only for inspection purposes, is probably unavoidable.

Sea Thermal Products

Neither the TRW nor the Lockheed investigators were asked to study the question of energy delivery to shore. Yet energy delivery is obviously of great significance for sea thermal power because the best plant sites, generally speaking, lie far from the biggest users of electricity.

A very important factor which most investigators have come to realize is that forms of energy other than electricity must be produced if the use of sea thermal power is ever to become widespread. One such use, first proposed by William E. Heronemus, professor of civil engineering at the University of Massachusetts and head of the university's sea thermal team, is the production of hydrogen at the plants by electrolysis. Many experts consider hydrogen theoretically the ideal synthetic fuel: It can be mixed with natural gas; it can power fuel cells; it can be burned in power plants; and, unlike electricity, it can be stored cheaply.

Other investigators, especially G. L. Dugger at the Applied Physics Laboratory at Johns Hopkins University, have proposed the production of ammonia, an energy-intensive product usually manufactured from natural gas. Dugger would combine nitrogen removed from the air with hydrogen produced by electrolysis to make ammonia.[7]

The most ambitious proposal so far has been made by the Andersons:[8] Fresh water, marine food, carbon dioxide, oxygen, and nitrogen could be produced with relatively little power consumption. Hydrogen, methanol, and ammonia could be produced using on-site power.

Fresh water is produced by vaporizing some of the used warm sea water and then condensing it with used cold water. Only 1 to 2 percent of the warm water passing through the plant would ordinarily be made into fresh water, according to Anderson. In a 100-megawatt plant, this would run to about 150 million gallons per day. At 20 cents per one thousand gallons, the fresh water could earn $11 million a year. Fresh water can be barged very cheaply. And in areas where fresh water is more valuable than electricity or synthetic fuels, plants could be designed to produce much larger amounts of fresh water.

A portion of the nutrient-rich cold water will be sufficiently warmed in condensing the fresh water for it to remain near the surface of the ocean, where it can be used in food-related projects. An experimental mariculture farm based on nutrient-rich cold water has been in operation on the island of St. Croix for several years.[9] Depending on the required number of tons of water per kilogram of fish, income could range from $7 million to $80 million per year.

The Andersons propose to deaerate the warm sea water before sending it through the heat exchangers, in order to control fouling of the exchangers by aerobic organisms. The components of the removed air – mainly oxygen, carbon dioxide, and nitrogen, which are present in higher concentrations in sea water than in the air above – could then be separated by refrigeration techniques. The yearly income from carbon

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Most researchers agree that the development of low-temperature heat exchangers, a relatively new field, presents the greatest challenge in the field of sea thermal power.

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dioxide is estimated at $32 million; from nitrogen, $6.5 million; and from oxygen, $5.5 million.

The electricity itself would be worth $17 million at 25 mills per kilowatt-hour. If the electricity is used for electrolysis, the resulting hydrogen, at $1,900 per ton, is worth $33 million. Additional oxygen worth $6.5 million would also be produced.

The synthetic fuel, methanol, can be produced by combining hydrogen from electrolysis with carbon dioxide, but at current prices such production is not profitable. Ammonia, which can be produced by combining hydrogen and nitrogen, would cost $170 per ton to produce and, again, may not be profitable at this time.

If gases such as hydrogen, oxygen, carbon dioxide, and nitrogen – all of which have important industrial uses – are produced on sea thermal plants, it may be a natural step for the plants to act as bases for major refining and manufacturing processes. The possibilities of ammonia and methanol production have been mentioned. Both Anderson and Dugger have proposed locating aluminum reduction factories on board sea thermal plants or nearby on shore. Several countries with large bauxite deposits, such as Jamaica, are in the tropics near the sea thermal resource. Yet, currently, bauxite ore is transported as far away as Canada, where it is then made into aluminum – an energy-wasting proposition. (Primary production of aluminum in the U.S., incidentally, accounted for about 12 percent of the total 1975 industrial electrical sales.) ERDA and the U.S. Maritime Administration have made grants for the study of the potential of sea thermal industrial complexes.

The main product of the first sea thermal plants, however, will probably be electricity. Hawaii, Puerto Rico, and Florida have sites near centers of high demand for electricity. According to a privately funded feasibility study,[4] underwater cable power transmission is feasible, costing $13 million for a twenty-mile cable system, or 5 to 10 percent of the total capital cost of a 100-megawatt plant.

Environmental Effects

Because the use of sea thermal power does not require extraction of fuel from the earth or burning of fuel in its operation, many of the environmental effects, such as air pollution and radioactive contamination, associated with nuclear and fossil-fueled power plants are not present. Nevertheless, one direct consequence which has been suggested by the Andersons is the heating of the ocean. It might seem, at first glance, that just the opposite would occur; that is, that the ocean's temperature would be lowered because of the removal of energy from the water. The Andersons hypothesize, however, that removal of the warmest water from the surface and its subsequent release into the ocean's depths (a necessary step in the sea thermal process) will enable more solar heat to enter the surface water, thereby slightly increasing the total heat in the ocean.

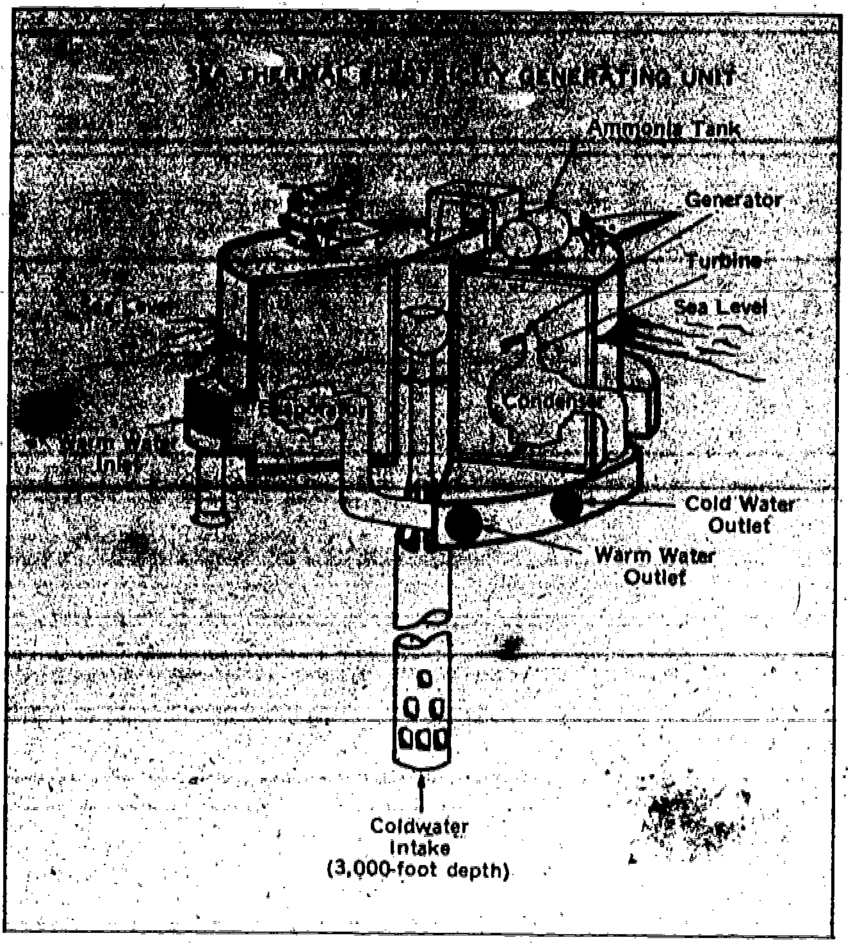
It should be stressed that the predicted temperature increases, even if the sea thermal resource were developed on a large scale, are so small that they can be measured in thousandths of degrees. Most other sea thermal investigators do not believe there will be any change at all in the amount of heat in the ocean. This, again, is an area which needs further study, both in regard to effects on marine life and on weather conditions. (Weather modification can be caused by even small alterations in the heat balance of the ocean.)

Another possible effect on marine life might be caused by a massive spill of the working fluid. Obviously, the effect would depend on the type of working fluid being used. Proposed so far are ammonia, the hydrocarbon propane, and any one of several heavy halocarbons. The possibility of such an accident, occurring, and its consequences, must be considered.

As mentioned earlier, local fertilization will occur as the result of warming of cold water through its use as a condensing agent. This is considered commercially beneficial. Still, it is also a major ecological stress the long-range effects of which are not fully understood. ERDA is supporting studies in the entire area of ecological consequences of sea thermal power.

World Impact

The results of developing an entirely new energy source would naturally be significant, as well as varied and unpredictable. Sea thermal power's economic effects on the tropics alone will be profound. Economic growth has historically been harmful to ecological balance, causing depletion of natural resources and fouling of the air, water, and soil. Environmentalists have under-



standably come to the conclusion that the populations of economically advanced nations must begin to learn to "do with less."

In this light, the alternative of sea thermal power offers several advantages: For instance, its widespread use would require, in some measure, clean oceans. The presence of oil slicks could foul the exchanger surfaces, making efficient use of the resource difficult. Corrosive chemicals in the sea water could shorten the life of the heat exchangers.

Another point in favor of sea thermal power is that it taps constantly replenished solar heat instead of releasing the concentrated stored heat accumulated over millions of years. The Lockheed report states:[10]

"The approximate 3 percent of the energy that OTEC extracts from the sea water passing through it at one time is a small amount, to be sure. But the balance of the energy is returned to the ocean reservoir where it is augmented by the sun and can be used again later."

ERDA (and, earlier, the NSF) deserves credit for making sea thermal power acceptable as a possible new energy source. Since the research program began in 1972, the federal support for it has approximately tripled each year; and from 1974 to 1975, it quadrupled to $3,000,000.

J. Hilbert Anderson, the earliest modern innovator in the field, believes the technology exists now for the design and construction of a 100-megawatt sea thermal plant which could be in operation within four or five years. It is his opinion that only the existence of a completed plant producing significant amounts of power will provide sufficient motivation to launch an intensive development program. Once launched, he believes, sea thermal power will prove to be the most important technological advance of the twentieth century. ☐

The title of this article as originally submitted was "Sea Thermal Power." The publisher and editors of Environment are responsible for the published titles and subtitles, selection of photographs and lead-in excerpts, photo captions, and preparation of most graphs and illustrations which appear in Environment articles.

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Power with Heliostats

A central receiver illuminated by a field of heliostats can absorb 10 to 100 megawatts of sunlight at 600° to 1000°K.

Alvin F. Hildebrandt and Lorin L. Vant-Hull

Many solar collectors presently on the market are suitable for providing domestic hot water and for heating homes. The higher quality energy required to effectively drive an air-conditioning cycle is proving somewhat more difficult to obtain with flat-plate collectors, but promising solutions are on the horizon. There is a general consensus that further increases in energy costs or collector performance coupled with the cost reductions resulting from mass production will result in a sizable domestic market for solar collectors, and substantial reductions in fossil fuel requirements for residential heating and cooling over the next 10 to 20 years.

We would like to consider here a much larger potential market, the electric and gas utilities. Consideration of turbine cycle efficiency leads to the obvious conclusion that to generate electricity effectively high-quality heat is required, for example, 300°C and higher. Similar temperatures are required to drive most useful thermochemical reactions. Such temperatures are beyond the range of flat-plate collectors and are marginal for linear-focus, concentrating collectors. A further requirement of an electric utility is that individual units produce on the order of 100 megawatts of electricity. Smaller units tend to be less efficient and more costly to purchase and to operate. To power such a unit requires the use of most of the solar energy incident on 3 to 5 square kilometers. The use of 20,000 to 40,000 tracking parabolic dishes, each concentrating energy on an individual heat engine, is one relatively complex alternative. A second alternative is to collect the thermal energy from such a distributed array of linear- or point-focus concentrators by means of a fluid and use it to operate a turbine. The combination of costs and heat losses associated with such a heat transport system can easily become prohibitive. A third alternative is to collect energy optically from a large area with the use of heliostats.

Heliostats—large, nominally flat, two-axis tracking mirrors—can be used to hold the image of the sun (helio) stationary (stat) on an elevated absorbing receiver continuously. This procedure permits the absorption in a working fluid of about 2/3 of the flux incident (taken as the product of about 1 kilowatt per square meter penetrating the atmosphere multiplied by the total mirror area). Because of the central focusing of energy from thousands of heliostats, the absorbed energy can be extracted from the receiver and delivered to the ground at a temperature and pressure suitable for driving a conventional utility-type steam turbine for electrical generation. Three large design studies (discussed below), currently nearing completion, have shown no substantive technical problems with this approach. Cost estimates show that no dramatic technical breakthroughs should be required to bring the cost of this system, once it is in mass production, into the range where it can compete with other environmentally benign power plants.

In the balance of this article, we shall discuss (i) the plan of our solar thermal power system or "solar power tower" based on optical transmission, (ii) the history of the solar tower, (iii) the receiver subsystem, (iv) the design of the heliostats and their placement in a field, (v) thermal storage, (vi) environmental concerns, and (vii) economics.

The Plan of the Solar Tower System

A tower supporting a solar receiver-boiler is located near the center of a field of mirrors or heliostats (Fig. 1). Radiant energy reflected from the sun is intercepted by the receiver and absorbed as heat on its surface. High-pressure water circulating through tubes forming this surface is converted to steam and returned to the ground. Here it may be used to power a 100-megawatt (electric) turbine generator set and simultaneously to charge a thermal storage unit for deferred operation.

Although differing in detail, a variety of systems consisting of an external receiver (as shown in Fig. 1) or a cavity receiver can be designed to have an overall efficiency of 2/3 for the conversion of the energy incident on the optical aperture of the system into thermal energy (available as high-pressure steam), where the reference is the mirror area multiplied by a representative direct beam insolation of 950 watts per square meter. Typically, 20,000 heliostats each 40 square meters in area are arrayed over an area of 3.5 square kilometers surrounding a receiver elevated 260 meters above the ground to provide 100 megawatts (electric). Such a system can deliver an annual average of 5.5 kilowatt-hours of steam energy per square meter of mirror area on clear days in the deserts of the U.S. Southwest.

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History of the Solar Tower Concept

The concentration of the direct beam component of sunlight with heliostats was first attributed to Archimedes, who instructed soldiers to reflect the sun onto the sail of an enemy vessel by carefully orienting their burnished shields (heliostats). Their efforts were successful, for the vessel was set afire. It was not until several thousand years later that Trombe and his co-workers added hydraulically controlled servomechanisms to an array of large heliostats to produce an automatically controlled 1-megawatt (thermal) solar collector (*1*). Interested in producing high temperatures to melt materials, Trombe added a large, fixed concentrator consisting of a parabolic dish and achieved a temperature of 4100°K. Baum *et al.* (*2*) investigated a tracking array consisting of heliostats on moving railroad cars, aimed at an elevated cavity-receiver-boiler. The cavity was to be rotated to face the heliostats throughout the day to achieve improved performance. They found that a prohibitive power requirement would arise because, at the very slow speeds involved, the wheels on the dusty railroad track would experience starting friction continuously.

Francia developed an intricate clock-driven field of 271 heliostats and was able to produce steam at a rate equivalent to 150 kilowatts (*3*). Using flat mirrors, he obtained an intensity somewhat less than 271 times the local beam component of direct sunlight, and with dished mirrors somewhat more. This concept is not suited for large-scale utilization of solar energy on a megawatt (electric) basis because it is impractical to connect many thousands of heliostats into a single clockwork device with sufficient precision. Moreover, the mechanism is not well suited to the larger mirrors required for an economical system design.

A reinvention involving a large number of heliostats took place in 1970–1971 at the University of Houston (*4*). [This work was supported by the RANN program of the National Science Foundation (NSF) beginning in 1973, and in 1975 it was transferred to ERDA (Energy Research and Development Administration) along with related investigations (*5*).] During our study of long-term problems in science and engineering, it became apparent that the outlook for energy sources beyond fossil fuels was hopeful but uncertain. Clearly, sol[illegible] energy could be utilized. Since some investigation of the possibilities had already been carried out, we considered only the most promising options. Photovoltaic cells were considered first but, because of their large cost and low efficiency at that time, were rejected in favor of potentially efficient thermal conversion cycles compatible with the utility grids. Steam-electric conversion cycles producing 100 to 300 megawatts (electric) are well developed by the utilities, which also have a large-scale distribution system. It seemed advisable to utilize available transmission methods.

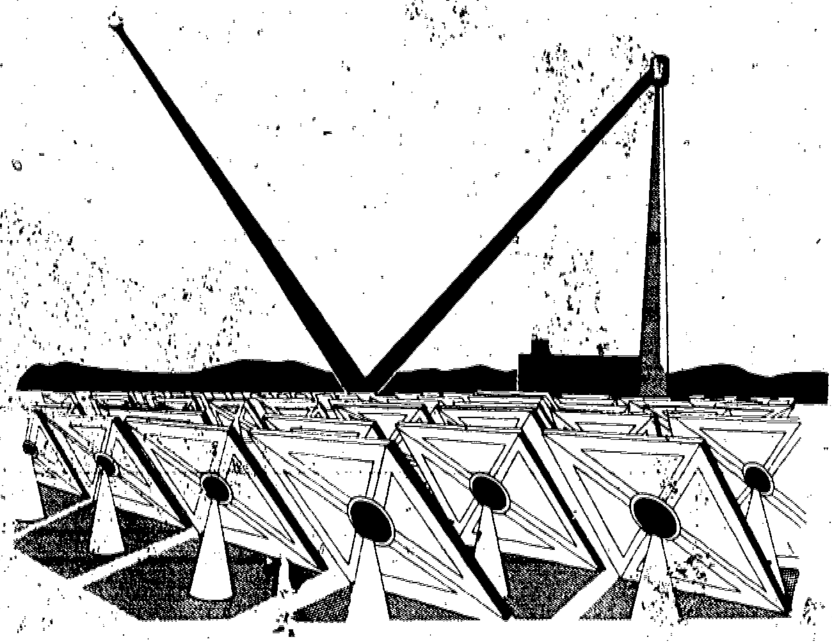

Fig. 1. The 100-megawatt (electric) heliostat power plant concept. The tower (260 meters high) near the center of the field has a boiler on top. About 20,000 heliostats (6.4 by 6.4 meters) would be required, spread over an area of about 3.5 square kilometers. A 10-megawatt (electric) pilot plant is under development by ERDA. Water is pumped up to the receiver and the steam is brought down to the conventional steam-electric generator usually employed by utilities.

The laws of physics tell us that the highest quality solar energy is obtained with a point-focusing device and that the radiative equilibrium temperature is limited to that of the source, in this case the sun at about 5720°K. To approach this temperature would require an ideal lens or a perfect-focusing mirror. Because large lenses require excessive bulk material, mirrors are preferable. Although many small focusing parabolas can be used, it is expensive to produce accurately curved mirror surfaces, and the required heat transport system entails substantial loss. Less loss would result if, using essentially flat mirror segments, we could have a single parabola with an aperture of about a square mile (2.6 square kilometers). In the 1950's Pilkington Brothers, L[illegible], developed an economic process for casting precision flat glass by slowly cooling a continuous sheet of molten glass while floating it on a bed of molten tin (*6*). The resulting strips of float glass, 3 to 4 meters wide, can be used to construct large, two-axis steered mirrors or heliostats as depicted in Fig. 1. An array of these heliostats constitutes what might be described as a tracking Fresnel reflector.

In discussions of the solar tower concept, the question of the "best" size system always arises. The correct answer to this question depends upon the assumptions made or requirements imposed at the onset. For example, one may assume focusing optics with the total of aberrations and other optical errors fixed at some design value. Typically, a standard deviation of 0.166° or 3 milliradians can be achieved at moderate cost (the solar disk subtends about 10 milliradians). For such a system the concentration is fixed by the rim angle of the collector and the geometry of the receiver and will not be affected by scale. Thus, one is then free to choose the "best" system based on thermodynamic cycle efficiency and the economics of producing the selected collector, receiver, and energy transport system.

A capacity of 30 to 100 megawatts (electric) at a single site is probably as small as the utilities would like to consider integrating into the grid because of synchronization, switching, and dispatching problems. One can generate this electricity with a single turbine, using energy from a field with an area of 1 square mile collected either optically (solar tower) or by means of a heat transport system to gather to a common point the energy absorbed by a distributed system of collectors. The distributed system of collectors may consist of either numerous minitowers or a multitude of individual collectors. As an alternative to this heat transport system, one can use either small turbines with each small distributed field or minitower or very small engines at the focus of parabolic dishes. We believe that these alternate approaches will be less efficient and less economical than the single tower approach. Heat losses in the smaller scale systems are much harder to deal with, and smaller heat engines currently available are appreciably less efficient than the large utility turbines. In addition, the parts associated with each reflector unit are markedly increased in number and complexity if one adds a small heat engine to each one, such as a Stirling, or Ericsson, cycle isothermal expansion and compression engine. The shorter focal length of the smaller systems also makes it necessary to use a larger number of more highly curved reflector segments to achieve the required 3-milliradian beam error including aberrations.

The choice between one or a few solar towers is less sharp. The cost of towers up to about 350 meters in height tends to scale with the corresponding collector area, becoming appreciably more expensive in the 400-meter range. Below 200 megawatts (electric) the tower cost does not significantly affect the argument. In the range from 10 to 200 megawatts (electric), suitable steam turbine generator costs and thermal-to-electric conversion efficiencies favor the larger sizes. A 10-megawatt (electric) generator would cost approximately $300 per kilowatt (electric) and have an efficiency of 35 percent, whereas the corresponding values at 100 megawatts (electric) are $250 and 40 percent. Consequently, under the stated assumptions, we would conclude that central receivers in the range from 50 to 200 megawatts (electric) are the most economical way to supply solar energy to an electrical grid.

This conclusion is reinforced by the fact that mirrors with a radius of curvature greater than a few hundred meters can be either stress-curved from flat sections or simulated adequately by a small number of facets, each canted at the appropriate angle. Either of these approaches is sure to be cheaper than casting self-supporting curved mirror segments of adequate optical quality to guarantee a high fraction of undistorted, specular reflection. For larger scale systems in the 50- to 200-megawatt (electric) range, the allowed segment size becomes equal to the 6-meter diameter of an economical heliostat, and nominally flat mirrors can be used. Removing the requirement for focus or canting segments relaxes a constraint on the heliostat design that will inevitably lead to lower cost heliostats and, consequently, a lower cost system.

For applications where a smaller amount of power is required at a local site, for example, a process heat or pumping requirement, other considerations come into play as well, such as the availability of a grid tie-in and the availability or requirement for reliable backup. Smaller units with a lower optical concentration will usually require lower operating temperatures to reduce convection and reradiation losses. In general, we believe that a single solar tower will be the most efficient, lowest cost, and most reliable means of supplying any solar requirement in the range from 1 to 1000 megawatts (thermal). Below 1 megawatt (thermal) a few parabolic dishes or troughs may be competitive. The only systems currently under development which may compete with the solar tower are the fixed reflector–moving receiver concepts. Although these are linear systems and so tend to provide lower concentration than is available with the "point focus" solar tower concept, these systems have the advantage of an emplaced reflector which does not require support or steering. After this advantage has been weighed against the disadvantage of a tracking receiver and relatively poor aperture utilization, a definitive comparison can, perhaps, be made. Because the reflector contour must be carved in the ground, individual collectors larger than a few megawatts are not practical. Thus for larger power requirements, the earlier arguments against distributed systems apply.

Aspects of the solar tower system—external or cavity receiver, flat or focusing heliostats, and methods of storage—are under study by a four-team ERDA effort to result in a preliminary design for a 10-megawatt (electric) pilot plant by June 1977 (7). Barstow, California, has been selected as the site for the pilot plant. It is anticipated that the first step in bringing costs for commercial solar plants into the range experienced for the construction and fueling of nuclear plants will be to increase plant size to at least 100 megawatts (electric) at a single site to achieve better collector and turbine efficiency. Figure 1 depicts the concept for a 100-megawatt (electric) demonstration plant (*7a*).

Other solar tower developments include pilot plants planned by the Electric Power Research Institute as well as the French and Japanese governments. An ERDA-funded Solar Thermal Test Facility (STTF) is under construction at Sandia Laboratory, Albuquerque, New Mexico, and is scheduled for completion in early 1978. The STTF is a small 5-megawatt (thermal) solar tower collector for testing the 10-megawatt (electric) pilot plant prototype components and performing related solar energy research.

The Design of the Heliostat Field

Because the heliostat field comprises about 50 percent of the total cost of a commercial solar tower system, design is crucial. For the 10-megawatt (electric) pilot plant there would be approximately 2000 heliostats, and for a 100-megawatt (electric) demonstration plant about 20,000 heliostats. The four design teams have all concluded that the most economical heliostats have an area of about 40 square meters and are composed of up to nine segments. For the pilot plant, the segments must be either curved or canted to provide an added degree of focusing. Important design factors are wind and gravity loading. The elevation and azimuth sensors and actuators must have a long life and will require only a fraction of a percent of the energy collected. The design should be suitable for mass production and easy installation.

The heliostats must be spaced in such a way as to avoid excessive shading of one another or blocking of the reflected radiation in the daily and yearly operation. Detailed computer analysis has shown that this can be accomplished for a nonuniform mirror distribution resulting in a ratio of reflector area to land area, ϕ, varying from 0.4 to 0.1 and averaging about 0.25. Far from the tower the heliostats must be sparsely distributed to prevent blocking of the reflected sunlight by adjacent heliostats. The heliostats are individually servo-controlled by a closed-loop sensor feedback system or by an open-loop computer control to reflect the solar beam onto the receiver all day.

A computer override initiates operation each morning and stow (shutdown) each night, sustains a uniform track in the event of a brief cloud interruption, initiates a rapid scram (shutdown) mode in case of coolant or boiler failure, or directs the heliostats to a safe orientation in case of adverse, inclement weather conditions. A vertical stow (orientation of the heliostat in a vertical position) can minimize hail damage or counter ice loading and, if the heliostats are facing downwind, can alleviate damage from blowing sand. A horizontal stow reduces structural specifications for surviving high winds, whereas a partially or totally inverted stow reduces the accumulation of dust. The heliostats are designed to withstand wind gusts to 170 kilometers per hour in horizontal stow. The possible requirement of an inverted stow is still under study and could add approximately 10 to 15 percent to the energy costs because of structural requirements in the heliostat mount and frame. A typical heliostat with sensor is shown in the far left of Fig. 2.

A map of the estimated direct annual beam radiation over the United States (Fig. 3) suggests why solar tower plants, as outlined, would be primarily situated in the desert Southwest. The heliostat system approximates a point-focus parabola and requires direct-beam radiation for imaging. The clear, dry, usually dust-free desert air ideally meets this requirement. As the solar elevation decreases, absorption due to the atmosphere increases; a useful number for the solar intensity when the sun is high overhead in clear days is 950 watts per square meter on a surface perpendicular to the rays. This is to be compared to about 1.35 kilowatts per square meter above the atmosphere.

Using a clear-air insolation model for an optimized heliostat layout, we obtain daily power curves as shown in Fig. 4 for flat ground at 35°N. However, favorable south slopes should be utilized where available. These calculations account for optical and thermal losses for a 100-megawatt (electric) generating plant with 6 hours of storage. While shading of heliostats and blocking of the reflected radiation is accounted for, losses can be kept negligible for solar elevations greater than about 25° by careful field layout. The mirror reflectivity is assumed to be 0.91 and the receiver absorptivity 0.95. Dust losses (5 percent) and radiation and convection losses (7 percent of the peak value) are also accounted for. The amount of energy transmitted into the working fluid varies with solar elevation from 2/3 to about 1/2 of the product of the solar intensity and the total area of the mirrors.

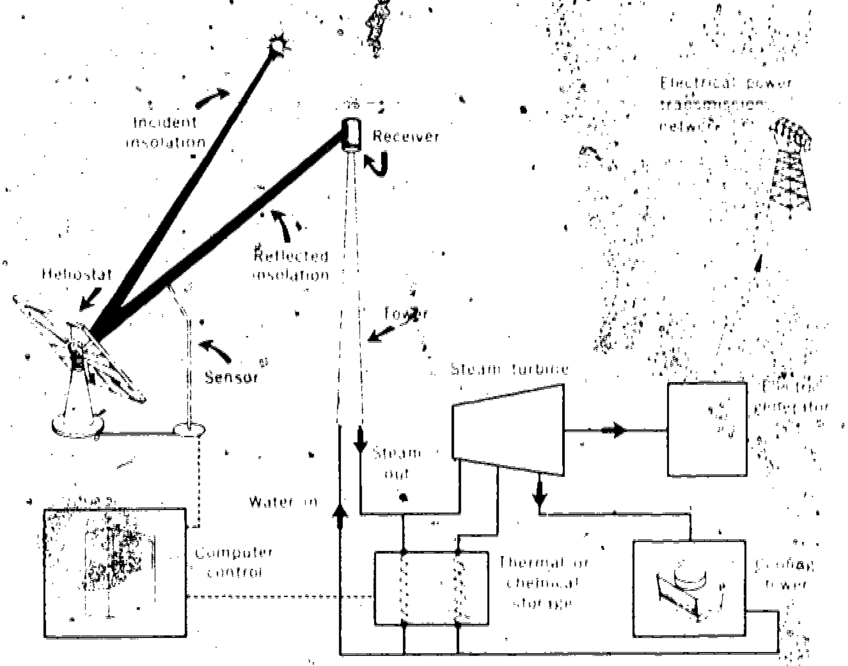

Fig. 2. Solar tower steam-electric power plant schematic. About 2000 heliostats would be required for the 10-megawatt (electric) pilot plant.

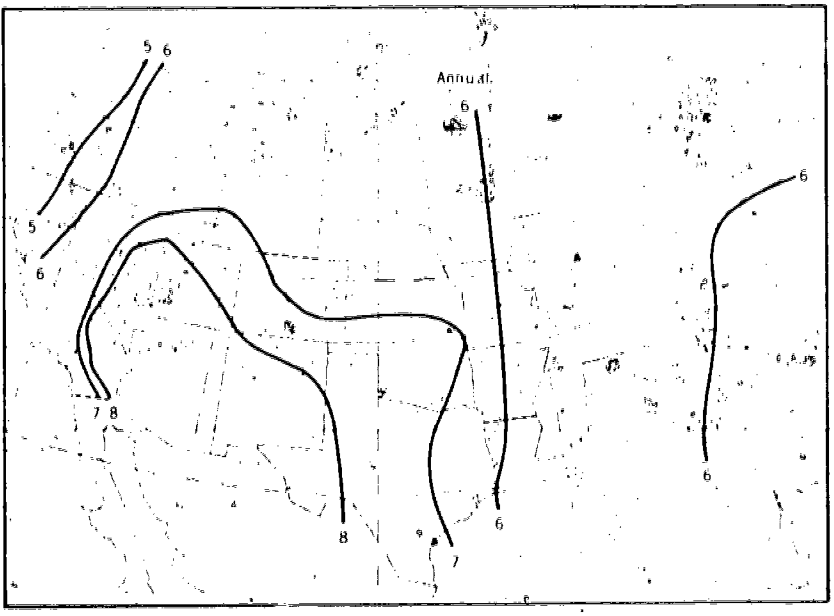

Fig. 3. Annual average direct-normal insolation (in kilowatt-hours per square meter) estimated from total hemispheric insolation (17).

The Receiver

The receiver subsystem must be able to effectively intercept the sunlight reflected from the heliostat field and absorb it as heat. The heat must be transferred to the receiver coolant at the desired temperature with minimal loss due to reradiation and convection. For a 100-megawatt (electric) commercial receiver we have determined that these requirements can be met effectively by a cylindrical receiver 17 meters in diameter and 25.5 meters tall, supported 230 to 300 meters above the heliostat field. The outside cylindrical wall forms the absorbing surface, which is made of 24 identical panels each 2.2 meters wide. For a water-steam receiver each panel will be composed of 170 Incoloy 800 tubes 13 millimeters in outside diameter connected to headers or manifolds at the top and bottom. The water will be transformed to superheated steam in a single pass through the receiver. The flow of preheated coolant through each panel will be independently controlled to compensate for variations in incident flux. Consequently, the output from all panels can be combined into a single downcomer. With normal design and insulation, the heat loss of this energy transport subsystem is insignificant. For the external receiver using water-steam as a working fluid, the outlet temperature is between 500° and 550°C. At this peak temperature a perfect blackbody can radiate only about 25 kilowatts per square meter, and convection losses, even in a strong wind, are only about half as great, for a maximum loss of less than 40 kilowatts per square meter. For the steam system the receiver flux will be reduced by a multipoint aim strategy in the pilot plant to about 300 kilowatts per square meter (600 in the commercial design). In each case the average flux (and mean loss) is about 2/3 the quoted value, so that the respective receiver losses are about 12 and 6 percent, respectively. The higher receiver temperatures tolerated in a receiver cooled with liquid sodium we have considered might double the thermal loss per square meter, but, since fluxes of up to 2 megawatts per square meter can be tolerated, a smaller receiver can be used so that the percentage loss would, in fact, be less.

A variety of cavity designs are under study as alternatives to the external receiver we describe here. These include tube type, multiple-pass, water-steam boilers; open-cycle air or closed-cycle helium ceramic tube or honeycomb surfaces; and cavities incorporating direct absorption in a molten salt flowing over the inner wall of the cavity. Although the cavities are likely to provide lower thermal losses, we prefer the external design for five basic reasons. (i) It has a very wide acceptance angle and so has less influence on the design of the heliostat field, the largest cost item in the entire system. The area of the cavity aperture, which radiates as a blackbody, must be kept small to retain any advantage. The acceptance cone half angle, θ, is therefore restricted to about 60° because the required radius of the aperture is (R cos θ), where R is the radius of the extreme beam. (ii) The cavity must be supported and insulated on its exterior surface. This exterior structure is substantially more massive than the interior support structure of the external receiver. (iii) Any one of the 24 modular panels of the external receiver can be replaced overnight, whereas the cavity would have to be serviced and repaired in situ. (iv) It is easy to design minimal constraint supports and structures for the exterior receiver panels, whereas the added complexity of the cavity boiler designs for the steam system tends to constrain the tubing, leading to excessive thermal stresses. (v) The lightweight components of the external receiver can more readily follow the variations in insolation due to clouds and other adverse weather conditions.

The Tower

For a 100-megawatt (electric) system, our analysis of the most cost-effective collector field geometry shows that the receiver must be elevated 260 meters above a field of heliostats with an area of 3.5 square kilometers. To support the considerable weight of the receiver and its steel support structure as well as the thermal transport system, we have chosen a tapered cylindrical-shell, slip-cast concrete structure. Inasmuch as this structure is designed to survive probable seismic disturbances in the West, it is sufficiently rigid to restrain sway of the receiver to less than 0.3 meter in winds occurring while the heliostats are operating. Sites near major seismic faults should be avoided because of the accompanying increase in the costs of the tower and heliostat supports. For most of the southwestern United States we have used a tower cost of $8 million.

Storage

Opponents of solar power insist that the solar tower concept should provide reliable power on cloudy days and also meet the nighttime baseload requirements. We believe that both of these requirements are unreasonable, at least in the early stages of development. Because thermal storage for cloudy days would be used only occasionally, the cost per cycle would be prohibitive. Although the storage system to provide for overnight operation would be used every day, the baseload application is the least competitive first use of solar energy. The market value of baseload electrical power is about half that of load-following power, that is, power that is generated to meet intermittent high demands, usually during the hours of 10 a.m. to 8 p.m. The electrical load parallels the solar supply (with a 2- to 4-hour delay); therefore, the most attractive first application is a plant designed for load-following with storage for 4 to 6 hours of operation to provide stable operation and to better match the observed utility load. A gas turbine plant with a low capital cost and a relatively high fuel cost can be added to the grid to supply the intermediate load power on the rare cloudy days when electrical demand is high.

The amount of thermal storage incorporated in the current design effort is sufficient to operate the turbogenerator for about 6 hours. This will permit penetration of the intermediate-to-peak-load utility market which usually occurs in the evening. Capacity credit will accrue to such a plant, and the storage will provide a cost-effective way of handling solar insolation differences in summer and winter. In the winter, a plant may be in the on-line, standby mode in the mornings so that the storage can be fully charged for evening operation, whereas

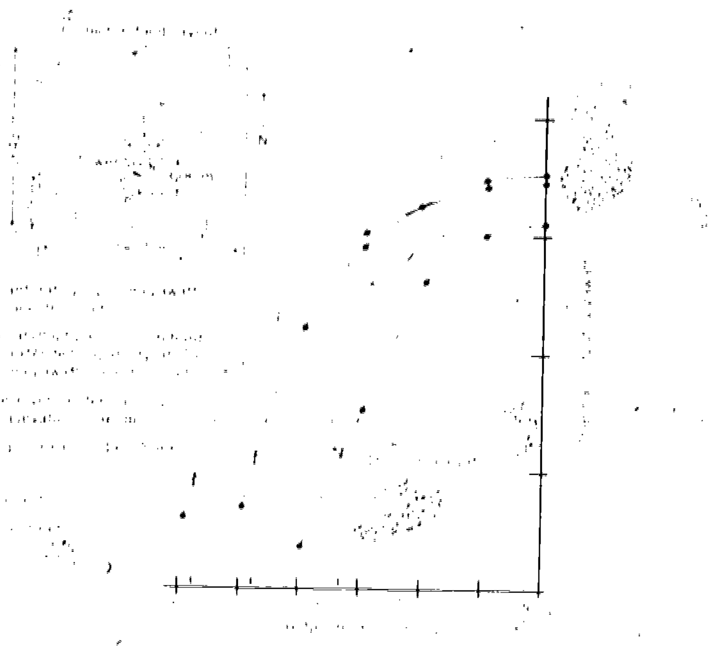

Fig. 4. Diurnal power curves for the field shown in the inset at 35°N. This field, coupled with 6 hours of thermal storage, would supply a 100-megawatt (electric) steam-electric generator. The thermal output, in 10^6 watts, is that deposited in the working fluid and includes loss estimates of 9 percent for reflectance, 5 percent for absorptivity, 5 percent average for dust, and 32 megawatts for combined convection and reradiation at the operating temperature of 515°C; Dm effective mirror diameter; δ angular standard deviation of the reflected light due to heliostat imperfections, Dr receiver diameter

in the summer there is sufficient daily energy to run at capacity all day and still charge the storage unit so that the evening market can also be supplied.

In an alternate mode of operation fossil fuels would be used when solar energy is not available, especially on cloudy days. Fossil fuels could also be used in the evening market, but some form of thermal storage is still required to ensure plant stability. Such a solar plant with fossil backup is classified as a fuel displacement plant and may be given little capacity credit. However, further depletion of our petroleum reserves may make such a facility acceptable. We have yet to develop an adequate methodology for estimating capacity credit for the solar component when fossil fuel is used in reserve.

A second form of storage is the use of suitable deep geological formations into which high-temperature fluids can be pumped. The requirement is a porous formation where leakage to the outside would be minimal, such as abandoned oil wells. Porous rock is a relatively good thermal insulator. If we consider a sufficiently large unit, the fractional loss per day is small because the surface-to-volume ratio becomes small. Calculation shows that geothermal storage for a 100-megawatt (electric) tower would require about 2 months to charge and then could be used cyclically each day to provide load-following capacity (*8*). Because the extraction is regenerative, injection and withdrawal temperatures could be very nearly equal and quite high. If, however, we should encounter difficulty in injecting or producing fluids at sufficiently high temperatures for power production, large quantities of process heat at 150°C and above are in demand and such geothermally stored heat can be harnessed to service those process needs.

Another approach to storage, which we believe deserves further emphasis, is chemical bond storage, with molecules having bond strengths of several electron volts per molecule. An obvious example is the electrolysis of water into hydrogen and oxygen. This method is under investigation for photovoltaic cells and wind energy systems but it is not the leading candidate if a thermal cycle is involved, because about 2/3 of the energy will be wasted in the thermodynamic cycle unless, perhaps, viable fuel cells are developed. The storage battery constitutes another form of chemical bond storage which is currently under intense study as electric storage for photovoltaic cells. Batteries provide more compact storage than hydrogen gas and are well suited for individual use, such as in an electric car.

Table 1. The 1977 cost estimates for a mass-produced 100-megawatt (electric) solar tower plant.

Subsystem*	Relative cost (%)
Generator plant	30
Energy storage (6 hours)	11
Installed heliostat costs ($80 per square meter)	43
Receiver, tower, and piping	14
Spares, land, and yard	2
Total system: $1700 ± 15 percent	100

The Germans have under development a closed-cycle, decomposition-recombination chemical reaction in which methane and water react to form hydrogen and carbon monoxide [the process bears the acronym EVA-ADAM (*9*); the hydrogen-generating reactor is called EVA (Einzelsphaltrorvernsuchsanlage), and the back reactor is called ADAM as the mate to EVA]. This reaction is to be coupled to high-temperature, nuclear gas reactors to deliver heat at a substantial distance. Calculations indicate that more heat can be delivered by this system than through a thermodynamic-to-electric cycle, and transmission costs are less than for electricity. This cycle can possibly be developed for use with the solar tower, but techniques for banking the catalysts (removing the reactants while maintaining the catalyst bed at operating temperature) during sunless hours must be studied. Moreover, the gases involved require large-volume storage.

A most attractive form of chemical storage is the simulation of fossil fuels. One would like to use solar heat to decompose a liquid compound into several other liquids that can be stored or transported and recombined at will with the liberation of heat, Q. The liquid-liquid reaction would offer ease of handling and would allow storage of more energy in a given volume than either a chemical cycle involving gas reactants or a sensible heat storage system. The heat generated in the reaction can be used in home heating and cooling and, if it is of sufficient quality, in the production of electricity. If we consider the reaction between ammonia (NH_3), water, and sulfur trioxide (SO_3),

$$NH_3 + H_2O + SO_3 \rightarrow NH_4HSO_4 + Q \qquad (1)$$

considerable heat is generated as the reaction processes exothermically to the right without a catalyst at temperatures up to 500°C (*10*). The chemicals are liquid at near room temperature and pressure (NH_3 requires some overpressure and SO_3 requires some heating to avoid solidification). The chemicals are cheap and abundant, and the density of energy storage is about 800 kilocalories per liter: about 1/7 that of gasoline or 10 to 20 times that of sensible heat stores.

Recycling of the chemicals would require the thermally activated decomposition of the ammonium hydrogen sulfate (NH_4HSO_4) into the compounds on the left in Eq. 1 and then separation. This back-reaction and separation have been carried out and at temperatures attainable with the solar tower (*10*). Basically, there is a temperature for each chemical system above which dissociation and absorption of energy occurs and below which the chemicals recombine with the release of energy. Such synthetic fuels can be readily integrated into our technological structure, displacing fossil fuels and bypassing the inefficient electrical generation cycle in many cases.

The development of methods for storage of sufficient energy to operate through several sunless days, or of a viable backup will probably be slow in coming, but, once such storage systems have been developed, solar plants in the Southwest can supply a significant amount of our national energy requirements by electrical transmission. The high-voltage direct-current net from the Northwest to the Southwest (1600 kilometers) is adequate demonstration that power can be economically transmitted over long distances. Therefore, it is possible to transmit power from Lubbock, Texas, in the sun-rich Southwest, to Detroit (1600 kilometers).

Environmental Concerns

For economic reasons, utilities have recommended the use of wet cooling systems in the pilot and demonstration plants. The dry cooling tower (Fig. 2) is somewhat more expensive and operates at a loss of a few points in plant efficiency, but dry cooling may be required to minimize environmental impact in the desert, a first-choice site for emplacement of the solar tower plants. With dry cooling towers, solar plants are expected to have a minimal environmental effect. In contrast to fossil-fired plants, the increase in global heat from a solar plant is a second-order effect since the system is simply converting incoming radiation to useful mechanical energy before it is ultimately deposited as heat by the electric utility. This figure compares favorably with conventional fossil-fired systems that deposit 3 to 4 units of thermal ener gy (waste heat) into the biosphere for each useful unit of energy utilized. In fact, continued dependence on nonsolar energy might eventually require the reflectance of sunlight back out into space to preserve the heat balance of the earth.

Economics

There are no technical barriers to the development of power with heliostats. The technology is available and plans are for a contract to be written with an engineering firm this year to initiate final design and construction of a first system, although it will be expensive. Cost estimates for the first-of-a-kind 10-megawatt (electric) pilot plant, scheduled to be completed in 1980, are in the range of $7,500 to $10,000 per kilowatt of installed electrical capacity, including provisions for thermal storage for 6 hours of operation beyond sunset (*11*). No dramatic technical discoveries are necessary to reduce this prototype cost by a factor of 5 to bring it into a range comparable to the $1000 per kilowatt (electric) currently required for the construction and fueling of nuclear plants.

A significant cost reduction will result from the better collector and turbine efficiency associated with an increase in plant size to 100 or 300 megawatts (electric). In addition, specific mass-production approaches have been identified which are likely to lead to the required cost reduction for an integrated large-scale, dedicated heliostat production facility. One such production facility would produce heliostats for ten 100-megawatt (electric) plants each year. If a facility sized to produce only one plant per year were built in 1985, a second in 1988, and an additional full-size production facility were built each year from 1990 to 2000, about 40 gigawatts (electric) of installed capacity could be online by the year 2000. This capacity is enough to meet the anticipated requirement for new intermediate electrical load for the entire Southwest and would require a land area of about 1400 square kilometers (550 square miles). Development of economic storage could expand this market manyfold.

Assuming at least 785 megawatts of capacity is constructed each year in an integrated and dedicated plant with a 30-year life, the midpoint cost of installed heliostats in 1975 dollars is $66 per square meter. Under the same assumptions, the total capital cost of a plant is given, in 1977 dollars, in Table 1. The $1700 per kilowatt (electric) includes 6 hours of thermal storage (*12*).

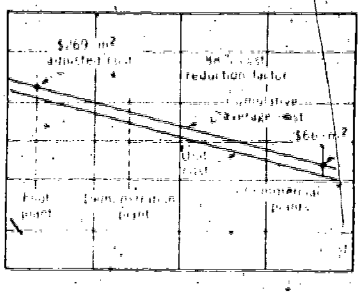

Fig. 5. Projected heliostat costs (1975 dollars). Mass-production learning would lower the average cost of $269 per square meter expected for the pilot plant heliostat to below $70 per square meter for commercial application after about 1 million units had been produced. This figure reflects projected cost reductions for a single facility resulting from integration of steel fabrication facilities, mirror and glass fabrication facilities, and experience-dictated improvements in plant operation, heliostat operation, and other factors. On the log-log scale, the upper line refers to the average value for all production to date, whereas the lower curve gives the cost projected for a single unit, which approaches $50 per square meter by the end of the production run of 25 to 30 years. (To convert to 1977 dollars multiply by 1.20.)

Once production of 100-megawatt (electric) units begins, costs would begin to drop as a result of learning curve effects. As an example, production of the first 10,000 Model T Fords resulted in an average cost, in constant 1958 dollars, of about $4000 for the cars produced in 1909. Continued cost improvement occurred in the manufacture of essentially the same car until 1927, at which time 14 million units had been produced. The cost for the last units of the production run was about $850 per unit (*13*). On the basis of this type of cost-reduction program, a reduction of 10 to 15 percent in the unit cost should be possible each time the total number of units produced is doubled until the bulk material costs predominate, and even then design refinements and new materials can further reduce costs. In Fig. 5 we show the anticipated learning curve for heliostats, where the upper curve represents the average cumulative cost for the entire production run and the lower curve is the unit production cost. Here $269 per square meter is the cost of the pilot plant and $66 per square meter is the average cost of heliostats produced by the plant after construction of approximately 20 gigawatts of capacity (1975 dollars).

Such a cost improvement permits us to put capital costs into perspective. A 10-megawatt (electric) pilot plant is estimated at $10,000 per kilowatt (electric) or less, whereas a first demonstration plant may cost $2500 per kilowatt (electric). To produce units selling in the range of $1700 per kilowatt (electric) requires that average heliostat costs, in 1977 dollars, be reduced to about $80 per square meter, which may require production of 5 million heliostats. In such a production run, the second million heliostats would already meet the cost requirements, having an average production cost of about $78 per square meter, whereas the first million would have an average cost of about $100 per square meter. Thus, the excess cost of the first million heliostats, each about 40 square meters in area and having an excess cost of $20 per square meter, is about $800 million. Compared to the expected cost of oil imports for 1977 of $40 billion, this is truly a small differential, which incidentally, will be paid back by even lower heliostat costs for the last 3 million heliostats produced in our hypothetical run of 5 million.

Since the cost of the heliostats is approximately half of the total cost of the commercial plant, less than $2 billion investment (subsidy) is required to stimulate a new technology that will integrate into the present utility structure. This amount should be compared to nuclear energy investments, recent space ventures, annual deficit of payments, 1976 oil import costs of $35 billion, and future escalation of oil costs.

There is sufficient unused desert land available in the United States to meet all of our energy needs by means of solar tower plants; an option not likely to be exercised. Energy production by solar towers would have an efficiency factor for land usage which would compare favorably with that of any renewable system presently under consideration. At a cost of $2000 per acre ($4900 per hectare), the land cost for a 100-megawatt (electric) plant is only $17 per kilowatt (electric).

Another indirect economic criterion is the energy amplification factor (EAF), defined as the useful energy produced over the useful life of a device divided by the capital energy required to create the device. Table 2 records an estimate of the energy required to produce materials, including transportation energy in manufacture and delivery, for the thermal component of a solar tower concentrator. Because this energy may have to be processed through a thermodynamic cycle with an efficiency of about 1/3, the collection time translates to less than 1 year. With the addition of the energy costs for fabrication, construction, and miscellaneous expenses, we expect the final required energy figure to be equivalent to less than 1.5 years, giving an EAF

Table 2. Material and transportation energy requirements for a 100-megawatt (electric) commercial solar tower system (fabrication and construction energy not included).

Part	Material (*12, 15*)	Weight (metric tons) (*12, 15*)	Energy required [megawatt-hours (thermal)]	Days to collect total energy	
				Thermal	Electric
28,605 heliostats (each 30.4 square meters)	Steel	23,084	144,055 (*18*)		
	Glass	13,959	45,196 (*16*)		
	Concrete	69,224	22,312 (*18*)		
	Sand	100,003	4,291		
	Polyurethane	257	715		
	Motors (copper)	372	8,152		
Receiver	Incoloy-800 and structural steel	1,127	7,655		
Riser and downcomer	Steel	182	1,135		
Tower	Concrete	41,757	13,517		
	Steel	1,266	7,899		
				70	210
Estimated transportation costs (*15*)			55,053	15	45
Total			309,980	85	255

of approximately 20 for a useful life of 30 years. This estimate can be compared to estimates for nuclear plants described in ERDA 76-1, where the EAF of a nuclear plant is estimated as 4 (*14*). Incidentally, the duty factor of the nuclear plant is taken realistically as 0.61, only 50 percent above the 0.41 expected for the solar plant with 6 hours of storage discussed here.

There still remains the energy cost of disposing of radioactive wastes and of shutting down a reactor after its useful life and safely disposing of the radioactive debris, whereas the steel used in heliostats can be reprocessed. The EAF factor clearly indicates a constraint which must be considered when deciding to build either nuclear or solar plants if the total fossil fuel requirements of the country are to be reduced over the next 25 years rather than expanded. The question of long-term economics requires the consideration not only of present dollars and capital development but also of long-term commitments to ensure both the availability of reliable sources of energy and the preservation of the environment.

The quantity of materials required in the solar tower design helps us to understand the economics of solar energy (Table 2). The heliostat cost of $66 per square meter appears reasonable if the cost of construction approximates $1 per pound or $2.25 per kilogram (for metal and glass). This represents an achievable goal, particularly if we realize that one can buy domestic pickup trucks in this country that sell for a little less than $1 per pound, and that a truck is a far more complex unit than a heliostat.

The cost of intermediate (load-following) power produced with the tower concept is estimated in the range of 80 mils per kilowatt-hour, based on a capital cost of $1700 per kilowatt (electric) and operating costs. We believe this cost is competitive. A charge of 30 percent was used for development of capital (the construction period is assumed to be 3 years), and the construction costs were amortized by means of a linearized fixed fee of 16 percent per year. Learning curve experience will lead to still lower capital costs for later production. The escalation of fuel costs will have no first-order effect upon constructed solar plants.

Conclusions

The estimated capital cost per kilowatt-hour of $1700 for solar tower plants is competitive with other means of energy production, such as hot-water nuclear reactors, including the complete fuel cycle. With 6 hours of thermal storage, the capacity factor is better than 0.41 compared to realistic capacity factors of 0.61 for nuclear reactors. Production costs seem reasonable, and there are no critical shortages of materials. Although there will obviously be improvements in design and management which will scale down costs, no radical technical discoveries are needed to construct and operate a solar energy plant. Once heliostats are in mass production, solar plant construction periods of only a few years are anticipated. The period for the construction of the pilot plant including final design is estimated at less than 3 years.

Most countries are in need of a long-range economic and political plan involving private enterprise and the federal government to develop a process for the national use of solar energy during the next hundred years. A national commitment would reduce the investment risk involved in building the first solar tower facilities. The greatest potential exists for adopting new technology in the utilities, but U.S. regulations essentially forbid the utilities to invest in new technology until it is proven over a period of time. Development of solar energy can reduce U.S. oil imports as well as help undeveloped countries that have no exports to offset the need for oil imports. A stable energy future demands that we examine all the energy options available.

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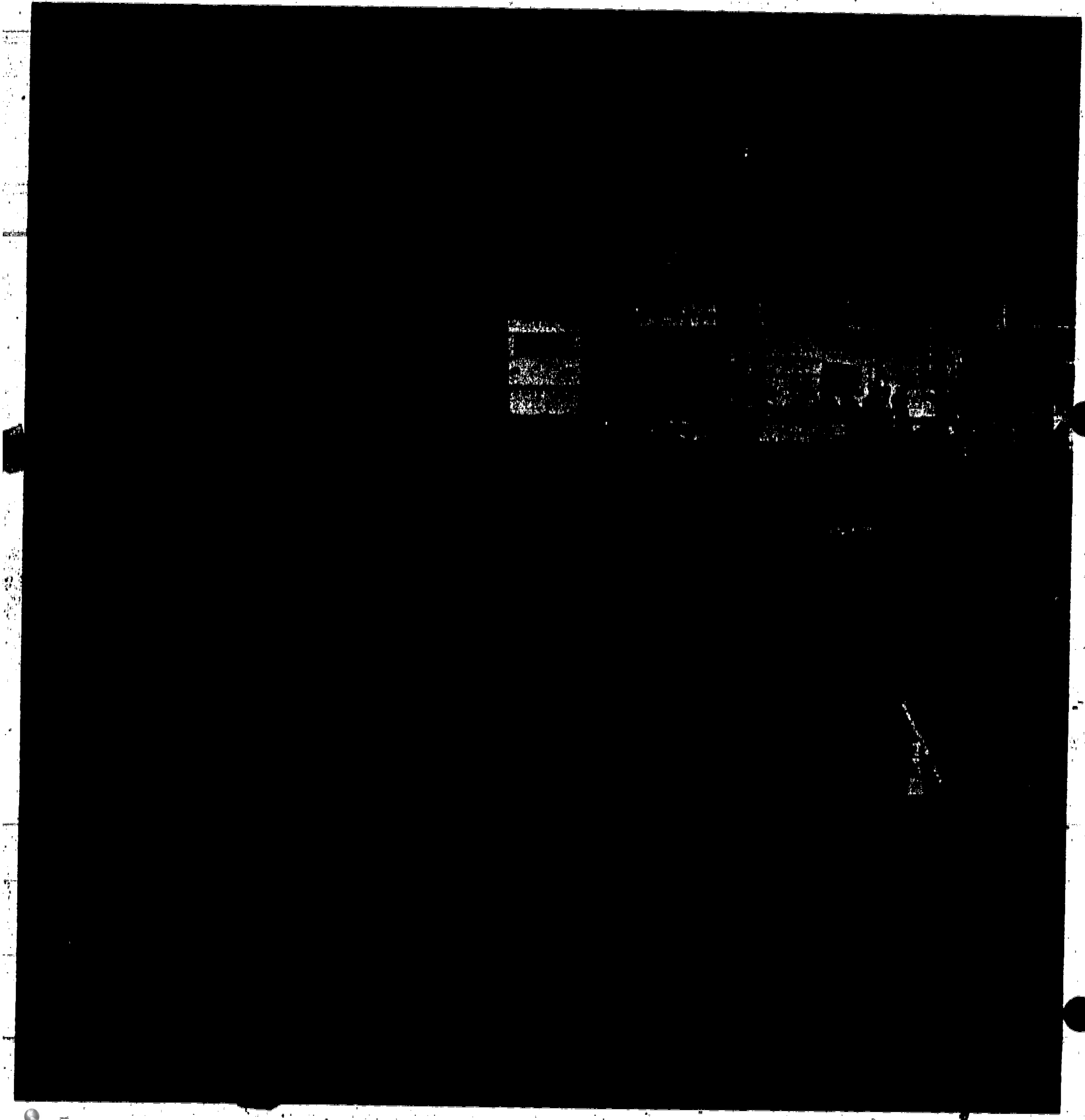
By David Morris

Solar cells find their niche in everyday life on Earth



If their cost continues to drop, we can one day have these space-age energy producers sprouting from our rooftops

The next time you buy a calculator, a wristwatch or even a new home, its electrical power source may be almost magical solar cells. These light-transforming wafers of silicon generate electricity silently, using nothing more than sunlight for fuel. They are beginning to supply electricity for commercial and agricultural uses in remote areas far from power lines. Although still in their infancy, it is increasingly likely that solar cells will become the centerpiece of our solar electric program and part of the answer to the energy crisis. Pioneers in this highly sophisticated field hope to provide low-cost electrical energy from rooftop solar panels by the mid-1980s, a development with profound implications regarding the utility industry and the nature of our neighborhoods and households.

Although the basic patents for solar cells were established in the early Forties, the first breakthrough in their manufacture came at Bell Laboratories in 1954. Bell's applications of one-meter solar arrays as voltage amplifiers was a pioneering step. The cells became more familiar in the 1960s, providing electrical power to spacecraft. Those used in the space program were very expensive, but cost was not the primary concern. With no other market, manufacturers had no incentive to lower the cost.

A few systems were established on Earth, using cells that had not met the requirements of the space program, but few cells designed for terrestrial use were produced until 1973.

Water spurts into an irrigation pond in a Nebraska cornfield, left. The pump is powered by the rows of solar cells at the right of the picture. Above, a technician checks batteries used for back-up power. This row of batteries will store about six hours of electricity; the pump does not run continuously.

Solar cells come down to Earth

Solar cells should not be confused with the solar collectors used to heat water and buildings and, by producing steam, to generate electricity. Collectors convert sunlight into heat; solar cells convert it directly into electricity. Sunlight striking the cells frees electrons, forming an electrical current.

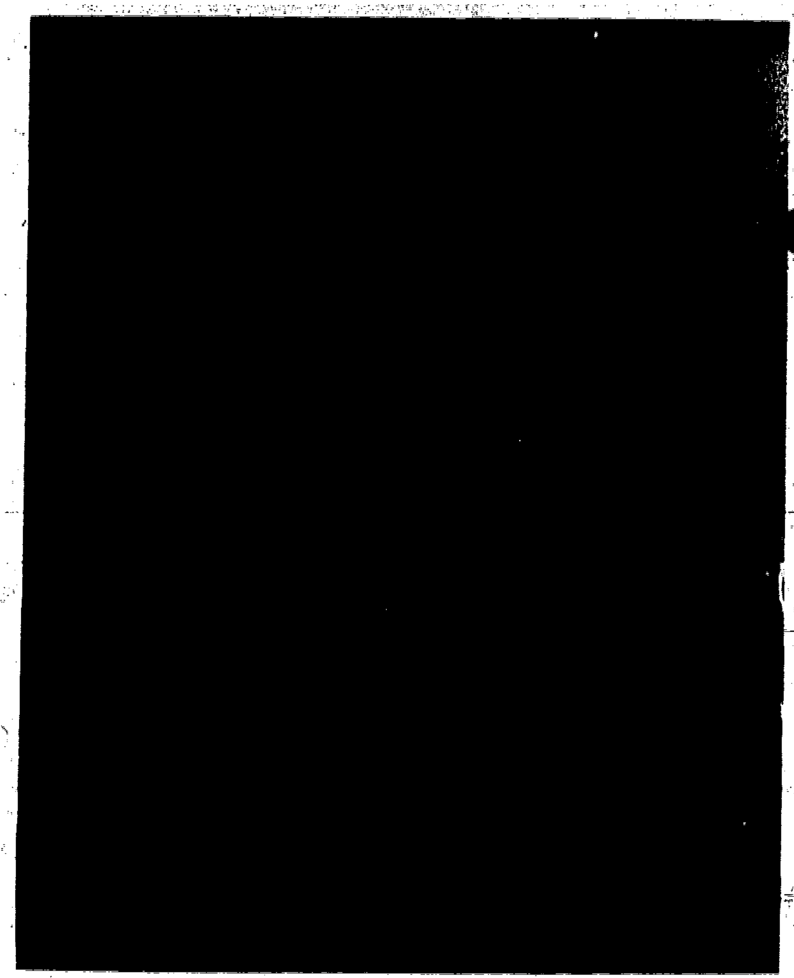
In space the sun is always shining, so there is no problem with storing electricity. On Earth, however, the sun shines only half the time in good weather and not at all in bad, so electricity must be stored for sunless periods. (Wind-powered electric systems have the same problem: electricity must be stored for times when there is no wind.) Currently this is done with lead-acid storage batteries, similar to those used in automobiles. A day's electricity for an average single-family house can be stored in batteries occupying the space of a closet; a row of such "closets" in the basement store power for sunless periods.

If, as some expect, solar cells come to be used in neighborhood-size rather than single-house systems, then storage, too, would be central. Two thousand homes would require about as much storage space as a million-gallon water tank, a not unfamiliar sight in many communities.

Present batteries present [illegible] problems (from the sulfuric acid in them) and are expensive: it takes about $40 worth of batteries to store one kilowatt hour. So along with the research on solar cells, a lot of work is being devoted to batteries using chemical reactions other than lead-acid.

Back-up systems can be used. A house fitted with solar cells can be left connected to the local utility; during sunless periods the house is simply switched over to the conventional source. (This way, the house can feed any surplus it produces back into the grid system as well; this is already happening with some wind systems.) And diesel generators can be used, just as they are now in hospitals and homes when the power fails in a storm or blackout.

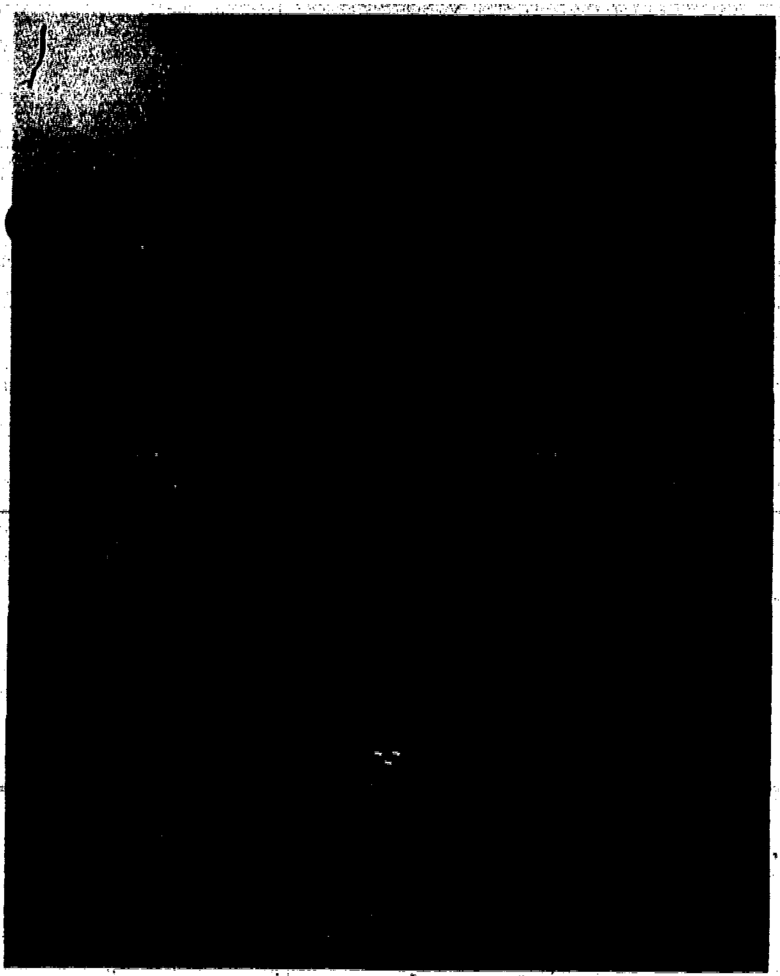
The author, codirector of the Institute for Local Self Reliance in Washington, is a columnist for Solar Age. *He coauthored* Neighborhood Power.



Viewed partly in a truck mirror, an array of solar cells provides electric power for a mobile

Large central systems generating electricity with solar cells or windmills can store power in other ways. One is to pump water up to a reservoir during periods of low demand, then let it run downhill through turbine generators when demand is high. Another is to extract hydrogen from water by electrolysis during low demand, then run gas turbines with the hydrogen during peak demand. Still another way is to use surplus power to spin huge flywheels, storing the energy as momentum.

Confident that storage problems will be solved, manufacturers are concentrating on making better and cheaper cells. The cells are extremely thin (12 thousandths of an inch). At present all commercial cells are made of silicon, the second most abundant element in the Earth's crust. But they can be made from other materials; two companies are about to produce cells made of cadmium sulfide. The largest cells made today are



Army telephone system. The Army is exploring other possibilities at Fort Belvoir, Virginia.

four inches in diameter. They are wired together in panels of dozens or hundreds.

The output of solar cells is often given in "peak watts," the amount of power produced in full sunlight at 77 degrees. A four-inch cell can provide slightly more than one peak watt at noon on a sunny day in an area such as Phoenix. Higher temperatures decrease the efficiency of silicon cells.

For many readers, a more relevant term may be "average wattage." The peak watt is what we get in ideal conditions; the average watt is what we get at any time, assuming adequate power storage. Over a year, we may average four to six hours of sunlight a day. Thus the ratio of peak to average is about five to one, a little less in Arizona, a little more in Minnesota.

The average single-family residence (a four-person, 1,500-square-foot, non-air-conditioned house) uses about 700 kilowatt hours a month, the equivalent of a one-kilowatt generator running continuously. Because this average house needs one kilowatt of average power, it requires five kilowatts of peak power. This, in turn, would require about 500 square feet of solar cells at present efficiency levels under optimum conditions. The Energy Research and Development Administration (ERDA) says 1,500 square feet would now be required in a northern area such as Boston.

In the last four years the price has dropped from $500 to $13.50 per peak watt. The cells are already cost-effective in remote areas, places where expensive heavy-duty batteries would otherwise have to be maintained and discarded regularly. Offshore oil platforms, buoys and remote weather and forestry stations are places where solar cells are now routinely used.

Most observers agree that the price will have to drop to a dollar or 50 cents per peak watt before solar cells on rooftops will be competitive with conventional central power plants.

The very recent entry into the marketplace by solar cells has produced a considerable gap in public understanding. Indeed, since 1974 the industry has advanced so rapidly that ERDA is reevaluating its programs. Henry Marvin, director of the Solar Energy Division, has assumed management of the solar cell or "photovoltaic" program. "The program was not keeping up with the technology," Marvin says. "ERDA was no longer pushing industry. It was no longer in front."

The price of purity

The very high cost of ultrapure semiconductor silicon has been a barrier to lowering the cost of solar cells. Metallurgical-grade silicon has a purity as high as 99.5 percent, and it costs 10 to 20 cents per pound, roughly the same cost as steel. The semiconductor-grade silicon, used in solar cells, however, has a purity of 99.99999 percent and costs $10 to $20 a pound. Microminiaturized circuitry demands this kind of purity, but it adds a great cost burden to solar cell manufacturers. Of the present $13.50 per peak watt, approximately $3.50 is for high-grade silicon.

Over the last three years, ERDA has chosen to concentrate on lowering the cost of the single-crystal process, in which each cell is sliced from a large, very pure, man-made silicon crystal. ERDA formerly believed that polycrystalline silicon, a cheaper, multiple-crystal form with lower purity levels, would have very low efficiencies. (Efficiency here means the percentage of energy in sunlight striking the cell that is converted into electricity. Present efficiency of single-crystal cells is 10 to 14 percent.)

Although many industry experts as recently as 1973 concluded that polycrystalline solar cells with a 10 percent efficiency could not be developed until at least 1983, two companies developed such cells independently in 1975.

Technology is changing faster than almost anyone realizes. In 1975, experts maintained that so much energy was required to make solar cells, they would not generate enough energy to pay back the initial ex-

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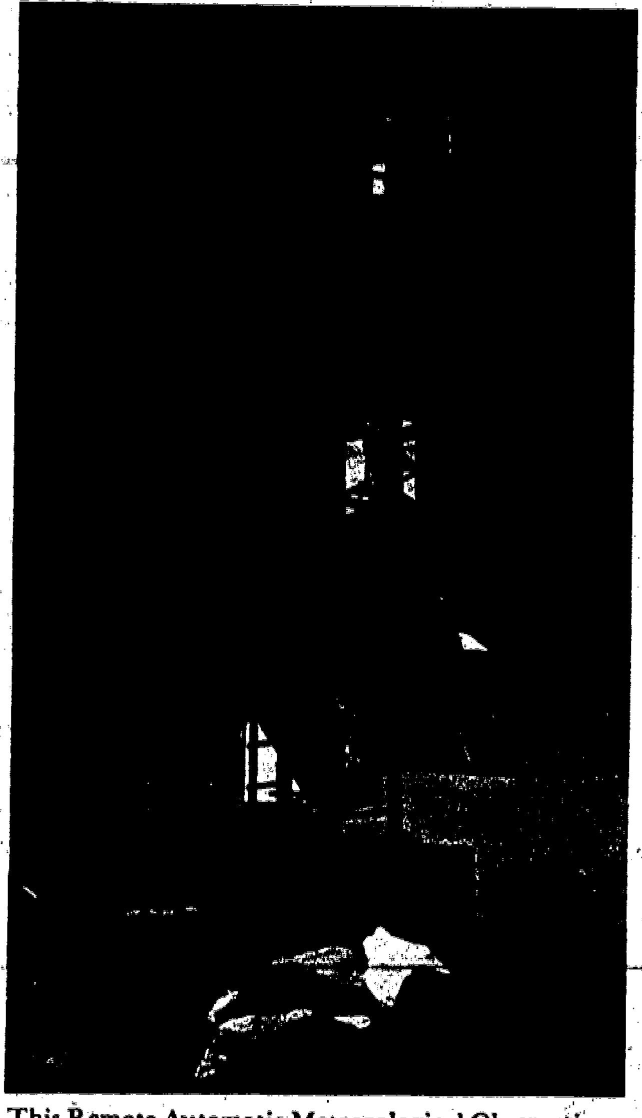
Panel at left sends a weak current through the steel reinforcement in these bridges, preventing corrosion.



This Remote Automatic Meteorological Observation Station is powered by solar panel near the bottom.

penditure within their 20-year lifetime. Yet a 1977 report done for the federal government on an actual production process not only found that the payback period was between four and six years, but went on to advocate the establishment of a solar breeder. A company could produce cells, put them on the roof, and use the electricity to make more cells. With slight refinements, many believe the payback period can be less than two years.

These rapid technological developments have the industry straining to transform technical developments into production-line processes. As one observer asked, "What good is a polycrystalline cell if it is not mass-produced and marketed?" Limited markets are delaying this step. A rapidly expanding market would permit manufacturers to invest the capital to automate their machinery and reduce prices.

It is unlikely that the market will open up very rapidly by itself. There are already thousands of locations where solar cells can be used economically, but the newness of the industry means every potential customer has to be educated anew.

Another marketing problem is the remote locations of existing solar-cell arrays. They grace the Arctic, Antarctic mountain peaks and north African deserts. No one sees them. One manufacturer laments, "The first national exposure for solar cells occurred when we installed some on a toilet facility in Yellowstone National Park."

Even in areas where solar cells are currently economical, their high initial cost makes local agencies hesitate. Few are experienced at considering costs over the lifetime of a system, a method of evaluation in which solar cells can be competitive. Many procurement officers appear to prefer to wait for a lower purchase price.

With the need to stimulate the market in mind, ERDA began direct purchasing of solar cells in 1975. It will purchase solar arrays capable of producing 160 to 200 kilowatts in 1977 and plans to buy more in fiscal 1978. Dick Weingarner of Optical Coating Laboratories, Inc., sums up the general feeling of manufacturers by saying, "It is good to see ERDA involved in direct buying, but this kind of national program will not bring the price down. Production levels need to be significantly higher before prices will fall significantly."

For many, the Department of Defense is the logical agency to make major purchases. A recent study identified military potential applications for solar cells as many times greater than current annual production. But the Defense Department has yet to be convinced that solar cells are superior to traditional diesel generators and battery systems.

In 1976 the ERDA photovoltaic budget (about $59.4 million) was many times the total sales of terrestrial solar cells (about $7 million last year). The agency bought 20 percent of the industry's output, spending the rest of the money for research and development.

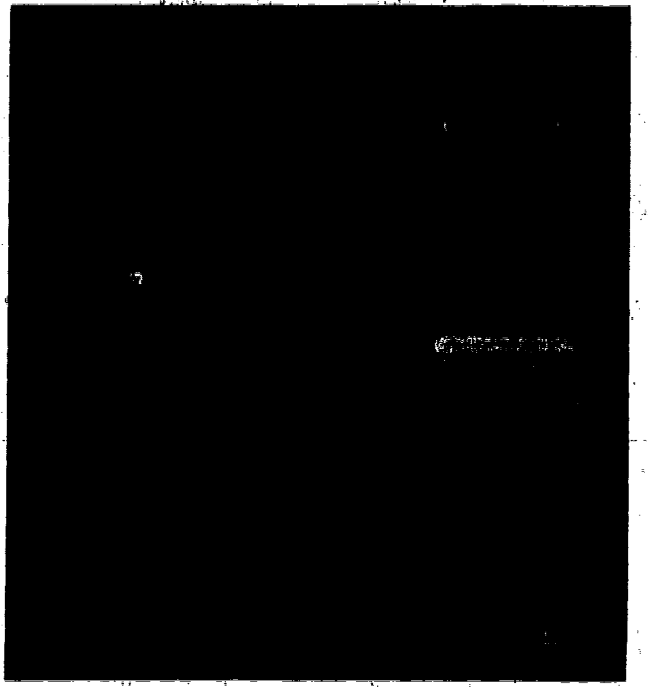
According to Dr. Marvin, ERDA will purchase $10 million of photovoltaic equipment in 1978 and spend another $30 million on research, development and overhead costs.

Raising the money

Congressional supporters have introduced legislation to increase substantially the level of federal purchases. The House approved a bill calling for a $39 million, three-year procurement program beginning in 1979. The Senate is discussing a $98 million purchase over the same time period.

Until now, however, the companies producing terrestrial solar cells have been relatively small. Big business has been reluctant to enter the solar-cell market aggressively. Mobil, Exxon, Shell, Hughes Aircraft and a French petroleum company do own solar-cell manufacturing or research companies, but to date few have been willing to invest the money needed to develop the market.

One of the most intriguing aspects of solar-cell development is their potential for decentralization. The cells operate most efficiently where the electricity is used. The farther they are from the consumer, the cheaper they must be to be competitive. While rooftop solar cells can be competitive with coal or nuclear power plants when the cell cost drops to 50 cents to $1 per peak watt, central solar plants would require a price drop to 20 cents.



In a remote Texas A&M farm field, solar cells power a trap used to sample insect populations.

Except for multistory buildings, the average rooftop has enough space to provide all the power needs of the building "with enough left over, say, to charge an electric car," noted Jerold Noel of Tyco Laboratories in 1974. Joseph Loferski of Brown University estimates that in Rhode Island 20 percent of the rooftop space could generate enough electricity to supply all of that state's needs.

ERDA predicts that a household system will cost $5,000 to $6,000 in 1985. It will supply all energy requirements except for a portion of the space heating. Is this the wave of the future? No one knows, but decentralization is a factor in the discussions.

Dr. Joseph Lindmayer, Solarex Corporation, told Congress: "The many letters we have received at Solarex and the many audiences we've addressed have convinced us that a major motivation for the growing popular support of solar energy is the fact that it can be controlled by individuals and local communities."

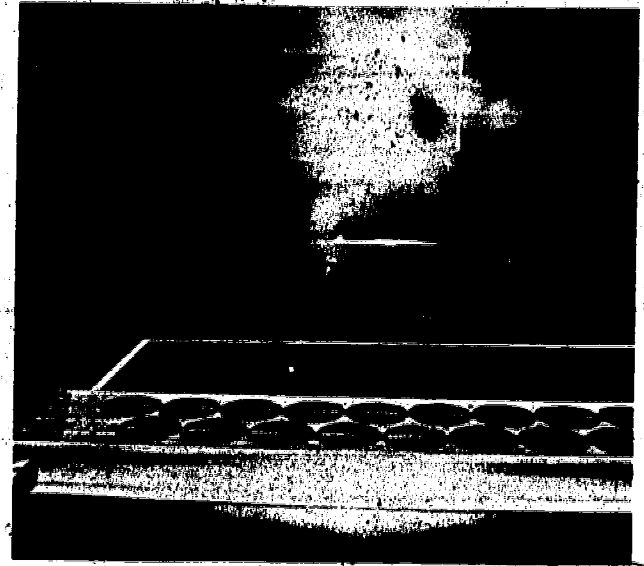
The utilities are studying solar-cell systems in three actual operations through their research association, the Electric Power Research Institute. Dr. Edward DeMeo of EPRI concedes the possibility of household systems, but believes centralized systems will prove more reliable. "I have some serious problems with individual rooftop arrays. One of the principal problems is maintenance. I don't think the individual will want to accept responsibility for his apparatus. We just don't operate like that. A possible scenario may be for the utility company or other organization to buy and install these on roofs and take care of maintenance. Once that step is taken it makes sense to try to aggregate the apparatus at some level, possibly one megawatt (200 households) in a central location purely for maintenance reasons and ease of installation."

The Office of Technology Assessment recently considered the decentralization issue: "If on-site energy equipment can be installed on a large scale at prices that are competitive with utility rates, a 30-year trend toward central power production would be reversed. . . . It would also challenge the premise on which existing regulatory law is founded: that because of economies of scale, utility companies are 'natural monopolies' and competition should be replaced by regulation to protect the public interest."

When the price of solar cells falls below eight dollars or five dollars per peak watt, they will become more widely used. The Agency for International Development and the World Bank have seriously explored the feasibility of using solar cells in those villages in developing countries where no electric grid system exists. Solar cells may become competitive for those applications within a year. Thus the solar industry will be building up experience in self-sufficient village systems in developing nations, before the price drops to where they are applicable in our own villages.

As the price drops still further, solar cells will become attractive for widespread use in industrialized countries. At 50 cents per peak watt the cost of electricity would be six to eight cents per kilowatt hour, comparable to costs in many cities now.

As noted above, however, central systems would require a cost of only 20 cents a peak watt. Whether this level can be reached is a point of considerable disagreement in the industry. Such a cost would translate into two dollars a square foot. No one is saying this isn't possible, but most agree that there must be some lower limit to solar-cell cost, and that decentralized applications will come first.

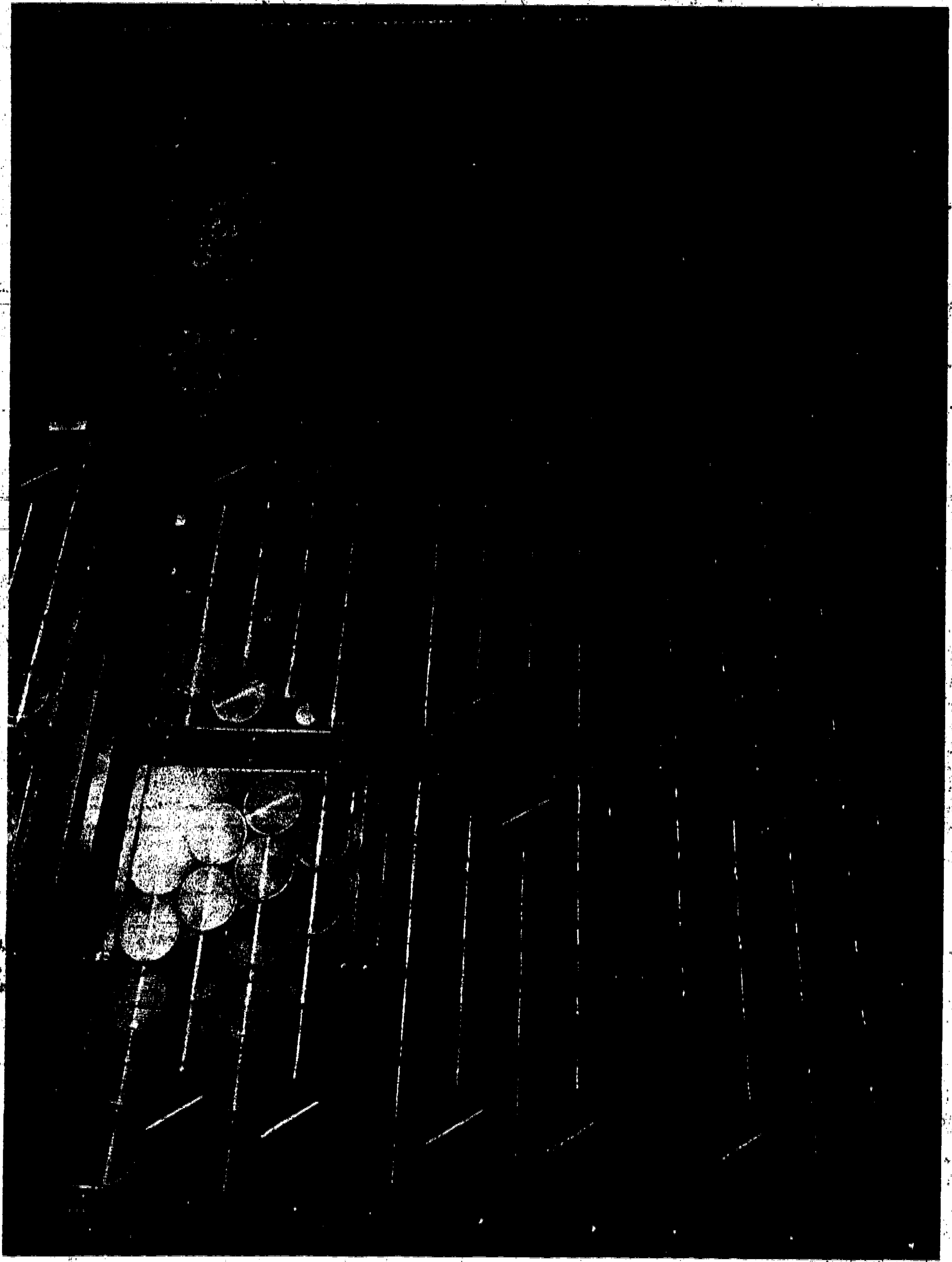


A panel of new solar cells is tested in a "black room" by being exposed to a simulated sun.

Some answers about solar cells may come from the community college project now under way in Blytheville, Arkansas. For the first time ERDA has awarded a contract directly to a user, which in turn has put together a technical team and is asking for bids from manufacturers. Integrated heat and photovoltaic systems are being used. The Mississippi County Community College will be designed to have a 250-kilowatt array that will use concentrating collectors. Light collectors will focus the sunlight onto the solar cells, getting more electricity from a given area of cell. Because the concentrator itself is less costly than the solar cell, the cost for the electricity should drop, perhaps to as low as $4.50 to $6 per peak watt. The system will also test a new type of battery, expected to be cheaper and more efficient.

The future of solar electricity looks bright. Considering that the first solar cells for use on Earth came off the production line in late 1973, the pace of development is extraordinary. Whether the market can increase rapidly enough to meet the price goals set forth in ERDA's national plan is the most pressing question. Yet each year, as the price continues to drop and the cost of conventional power continues to rise, these tiny devices demand more attention in all of our future energy planning.

In another Army test, these solar cells produce 11 kilowatts to power a water purification system. Other tests involve radio and radar power supplies.



BY PAUL N. CHEREMISINOFF AND ANGELO C. MORRESI

ENERGY FROM WOOD WASTES

Use that tree

ADVOCATES OF ALTERNATE energy sources have begun to examine the wood-processing industry as an energy reservoir. Wood at one time was the primary fuel of the country, but because of its relatively low heating value as compared to coal and oil it dropped from use. However, rising gas, oil, coal, and disposal prices have resulted in renewed interest in wood as a fuel.

Each year, tremendous quantities of timber are harvested across the country to be processed into lumber, plywood, or pulp. These wood operations generate large volumes of wood and bark residues, and some utilization of these residues has been accomplished through reprocessing into pulp, pulp products, composition board, and sometimes fuel. Wastes from the logging operations themselves, however, are almost entirely neglected except for disposal concerns. Table 1 gives the amount of unused forest residue annually available in the U.S.

Wood wastes generated during the processing of logs into products can amount to 1.25 dry tons (weight after thorough drying) per 1,000 feet of lumber cut and 0.5 dry ton per 1,000 feet of 3/8-inch plywood produced. In mills in the Pacific Northwest, nearly 23 million dry tons of these materials are produced annually, with 7 million dry tons going unused.

Other wood residues that are potentially available include: (1) fire-damaged and insect- or disease-ridden trees in urban areas, (2) driftwood, (3) construction wood wastes, and (4) the wood portion of municipal solid wastes.

TABLE 1

ESTIMATE OF FOREST RESIDUES PRODUCED IN THE U.S. ANNUALLY (BILLION CUBIC FEET)

	Volume	
Source of Residue	Available	Possibly Recoverable
Residue from logging operations	3.5	3.0
Fire-, disease-, and insect-damaged timber	4.5	2.0
Unused, precommercial thinning	1.5	1.0
TOTAL	9.5	6.0

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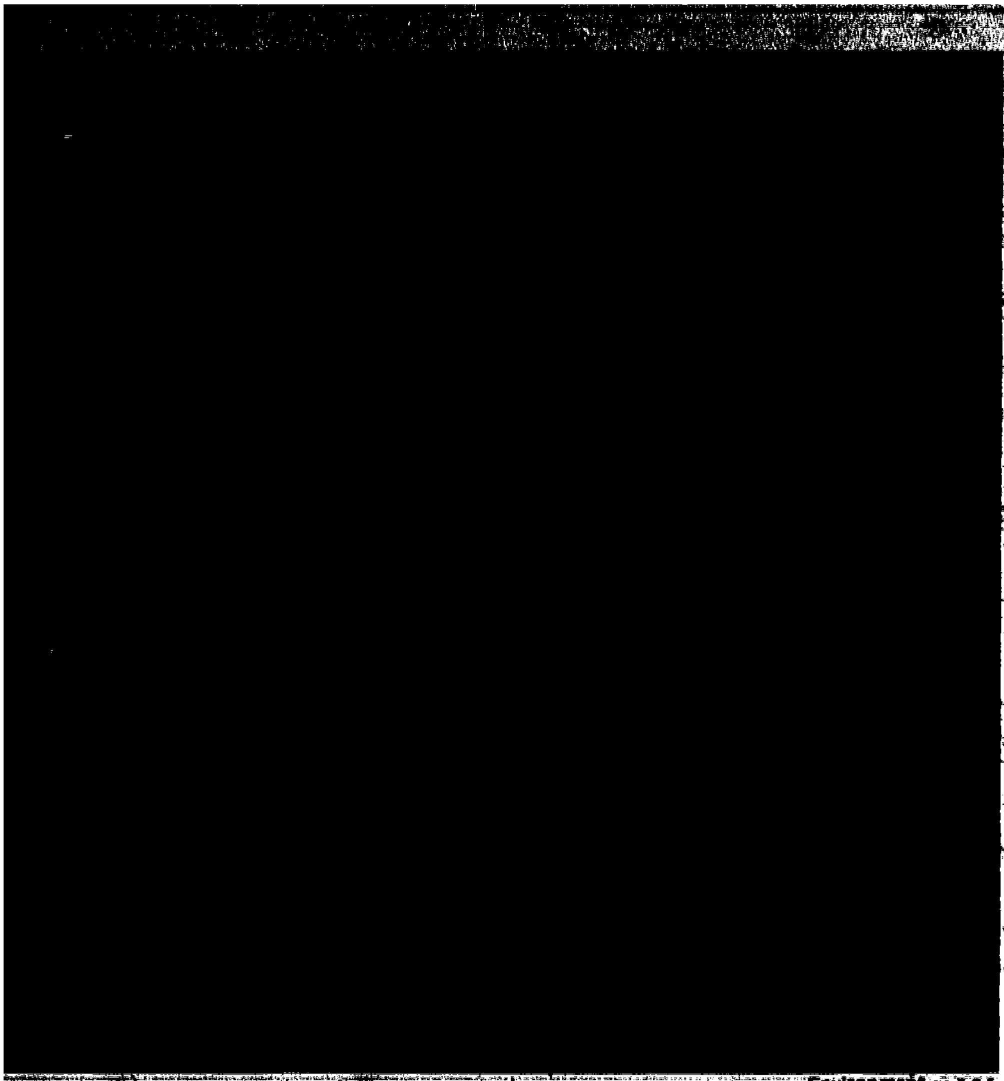


Aside from the wastefulness of incinerating wood by-products, this Canadian lumber mill is also contributing to air pollution.

Environment — r.c.s.

These wood and bark residues have widespread usage in a variety of applications. The demand for products which can utilize wood residues as a raw material is continuously rising. Depending on the residue size and quality, they can be used in the manufacture of plywood, lumber, paper and pulp, and building boards.

The demand for forest wood in the U.S. will increase from about twelve billion cubic feet in 1970 to nearly twenty billion cubic feet in 2000. With increased housing requirements, the domestic demand for lumber is expected to increase dramatically through 1980, after which the demand increase will be less significant. Domestic production of lumber in 1970 was 34.7 billion board feet (a board foot is a unit of lumber measuring 12 x 12 x 1 inches). The accelerated construction pace and continued rise in the manufacture of wood products will cause plywood and building board usage to more than double and triple, respectively, by 2000. The more virgin wood is used, the more wood wastes are generated.

A significant portion of increased composition board demand is expected to be satisfied through the use of wood residues as raw materials. Wood wastes are also expected to help satisfy a 2.4 fold increase in paper, cardboard, and pulp products; 72 million dry tons of softwood chips were used by the paper and pulp industry in the U.S. in 1972. At the present time, this industry uses wood wastes for about 30 percent of its raw materials. Wood wastes supplied about 76 percent of the Pacific Coast pulp industry's raw material requirements.

Availability of Wastes

Thus, wood residues are available and will continue to be available throughout this century. They have been utilized to some extent and are expected to have increased usage in the future. However, their utilization is somewhat dependent on the consumer industry's proximity to the waste reservoir. The paper and pulp industry of the Northwest can readily use the waste wood resource because large quantities of milling and logging residues are generated in this region. Other locations across the U.S. which house paper and pulp and composition board companies do not have these wood residues as a cheap and readily available raw material. For these plants to utilize wood wastes in product manufacturing, the additional handling and transportation costs must be considered.

Although these wood and bark residues can and do have widespread usage in a variety of applications, the ultimate determining factor in their usage is cost. The economics may prove to be unfeasible for a relatively small milling plant to reuse or have its wood wastes reused. Furthermore, the large plants which generate huge volumes of wood residues may not have an outlet for these wastes. When the utilization of wood and bark residue becomes uneconomical, a disposal problem is created. The use of these materials as a fuel may prove to be a viable alternative.

The seven million dry tons of wood and bark wastes generated on the Pacific Coast could replace conventional fuels at milling facilities for their processing and operational heat requirements. Table 2 gives some characteristics and the heating values of typical wood residues. Figure 1 shows the moisture content of some western woods and barks in pounds per cubic foot.

Clearly, wood residues vary in size and composition. Sizes of wood residues range from dust particles generated by sanding to large chips and slabs. The moisture content of the sander dust is relatively small as oppared to the moisture content of some woods which exceeds 50 percent.

To utilize wood residues for fuel or any application, they must first be reduced to a size that can be handled conveniently. Large volumes of wood and bark residues can be effectively reduced in size by a "hog" machine (a mechanical shredder). The particles produced by this piece of equipment are commonly referred to as hogged fuel or hog fuel. Hogged fuel can include any portion of wood or bark residues in a reduced particle size. Additives to the hogged fuel may also include sawdust, wood shavings, and ground bark. Hogged fuel may be a conglomerate of many types of wood wastes.[1]

Wood Waste for Fuel

Hogged fuel, particularly in the northwestern region of the U.S., is usually sold in bulk volumes, or units (a unit of wood residue is the amount contained in a volume of 200 cubic feet). A unit of hogged fuel contains roughly a ton (dry) of wood material. This dry weight can vary from 2,600 pounds for hogged Douglas fir bark to 1,900 pounds for sawdust to 1,200 pounds for Douglas fir shavings.

The potential for wood residue fuel is already recognized in the Pacific Northwest. Estimates of wood residues from Oregon sawmills and plywood operations that were used for fuel in 1967 amounted to four million dry tons, or about 27 percent of the total residues generated. The heat content of those residues used for fuel was 70×10^{12} Btu, which is equivalent to the heat from the total sales of the Northwest Natural Gas Company in 1967. Western Oregon and parts of Washington are supplied natural gas by this company.

In the Tennessee Valley Authority region, the total amount of unused wood residues produced from land clearing and industrial operations in 1970 was over 12.3 million tons.[2] The heating value of this residue is equivalent to 4.9 million tons of coal, which, at $20 per ton, would be worth $98 million. Thus, availability of these wood residues is of such magnitude

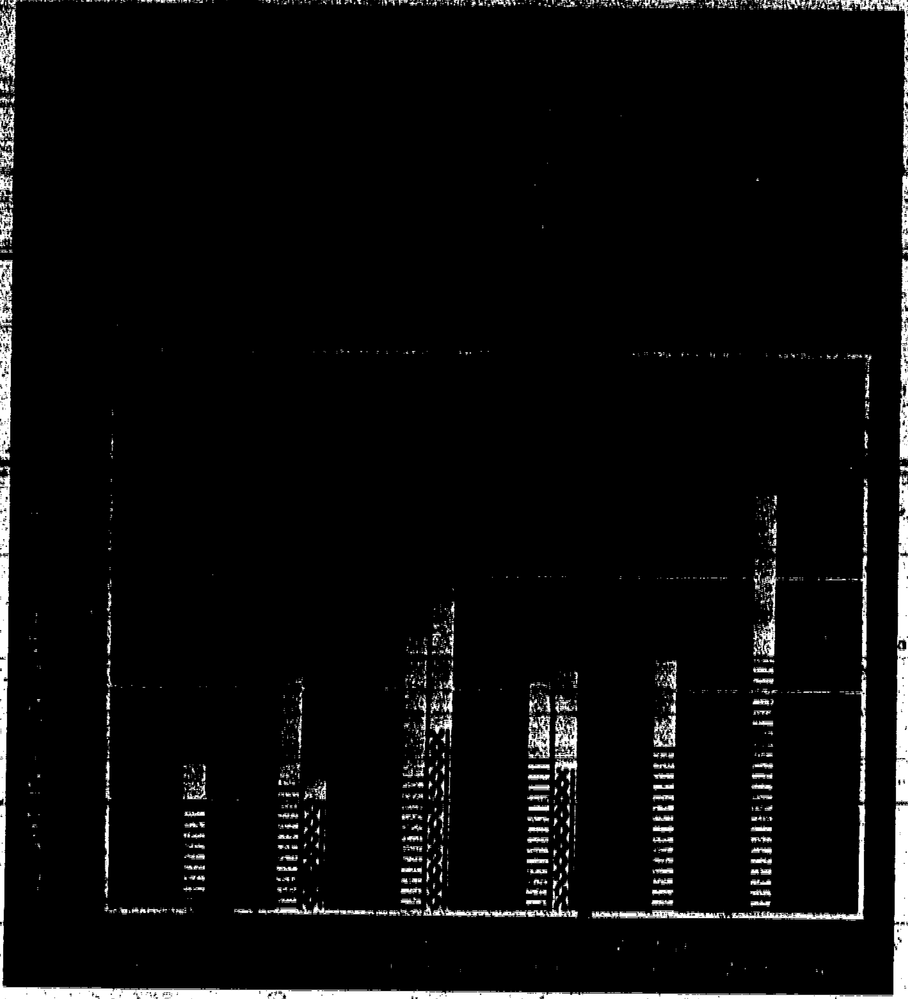


FIGURE 1

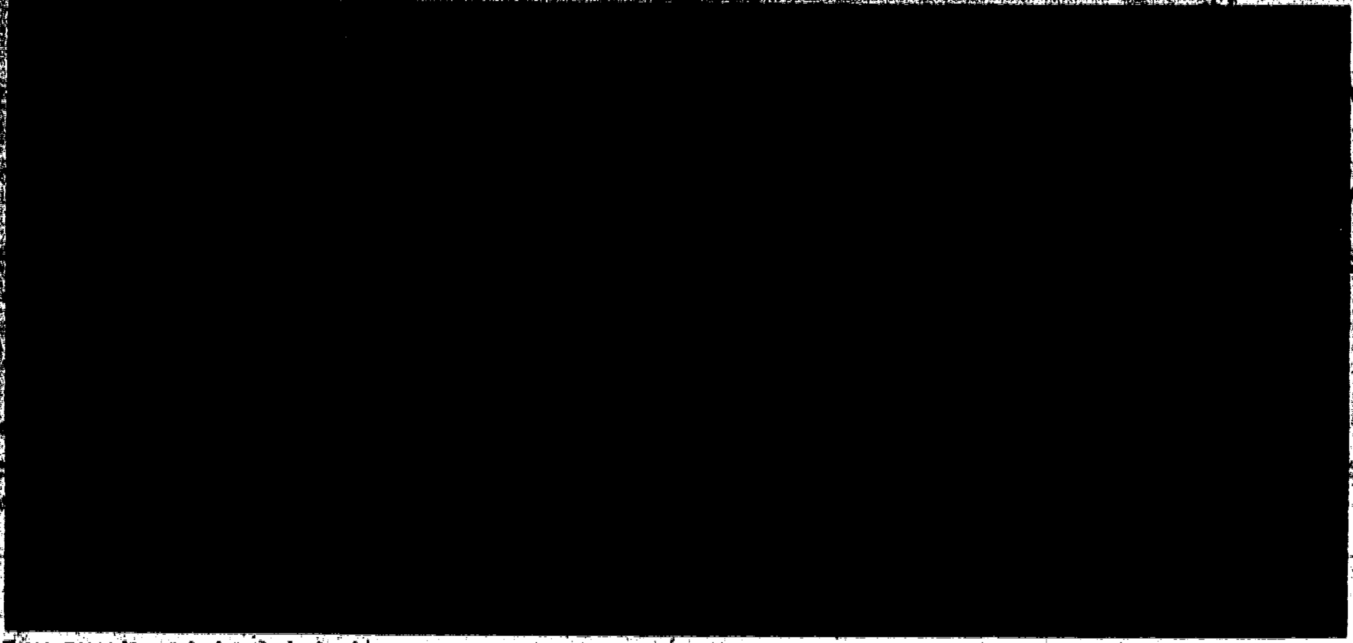
MOISTURE CONTENT AND DRY WEIGHT OF WOOD FROM CERTAIN COMMON TREES[1]

TABLE 2

HEATING VALUES OF SOME TYPICAL PACIFIC COASTAL WOOD RESIDUES

Kind of Wood or Bark	Heating Value (Btu per Dry Pound)
Douglas Fir	
Wood	8,900
Bark	9,800
Western Hemlock	
Wood	8,400
Bark	9,400
Ponderosa Pine	
Wood	9,100
Bark	9,100
True Firs	
White fir wood	8,200
Western Redcedar	
Wood	9,700

Source: Reference 1.


© McMillan Associates

Trees measuring up to twenty inches in diameter can be chipped in less than a minute with this mechanical shredder.

that their utilization as a fuel or fuel supplement is becoming imperative.

In the combustion of wood and bark three processes occur: (1) Heat must be supplied to evaporate the water in the wood fuel in order to effect combustion – the amount of water in the dry wood thus is an important property since, as the moisture content is increased, the heat content is proportionately decreased; (2) volatile hydrocarbon gases are then evolved and mixed with oxygen, giving off heat; and (3) more heat is released and combustion completed with the reaction of oxygen with the fixed carbon at high temperatures. Initially, these processes occur in succession, but as heat is generated the wood eventually begins to sustain its own combustion, and all processes occur at once.

The stochiometric air requirement of a combustion process is that amount of air necessary to burn the carbon and hydrogen in the fuel completely to carbon dioxide and water. Depending on the moisture content, stochiometric air requirements vary, and, naturally, so does the weight of the resulting stack gases.

Many firms today already use wood and bark residue fuels. These residues are also burned for home heating in stoves, furnaces, and fireplaces. The heat of combustion of sander dust is used in veneer and wood particle drying processes and for the production of steam, which represents the largest industrial use of wood and bark fuels. Steam is produced for heating, processing, and generation of electricity. Hog-fueled steam plants range in steam capacity from 10,000 pounds per hour to over 500,000 pounds per hour.

Burning the Fuel

Probably the most common hogged wood fuel burning process involves the use of a dutch oven. In the first stage, water in the wood is evaporated, and the fuel is gasified. In the second stage, furnace combustion is completed. The system is gravity-fed, as the hogged fuel enters the dutch oven from above and forms a conical pile. The dutch oven was in widespread use until about 25 years ago. Presently, more efficient and larger-capacity systems are available.

The demand for forest wood in the U.S. will increase from about twelve billion cubic feet in 1970 to nearly twenty billion cubic feet in 2000.

The fuel cell process is also a two-stage furnace, as illustrated in Figure 2. The wood fuel enters the primary furnace compartment from overhead. The gravity-fed system allows the fuel to drop onto a water cooled grate. The wood is first gasified in the primary stage, and the gases pass into a secondary combustion compartment for complete combustion. Wood-fuel boilers of this type are in rather widespread use throughout the western U.S. Labor operating costs are low because these steam plants are highly automated. Low operating pressures of about 25 pounds per square inch give these plants steam capacities ranging from 10,000 to 30,000 pounds per hour. When the moisture content of the fuel is above 50 percent, hogged-fuel dryers are necessary. Many of these wood steam plants have applications in drying kiln processes.

Many steam plants recently constructed to be wood- or bark-fueled are the spreader-stoker type. In the spreader-stoker system, a pneumatic or mechanical spreader feeds the wood fuel from above onto a grate in the furnace. As the fuel falls to the grate, it is partially combusted while in suspension. Combustion of the fuel is completed on the grate. This operation can be used with small plants to obtain steam rates of about 25,000 pounds per hour or with large capacity plants to obtain 500,000 pounds per hour.

The inclined grate furnace system is

very similar to many municipal solid-waste incineration methods. At the furnace inlet, the hogged fuel is deposited on the top section of the grate. The wood fuel then passes through the three zones of the grate. The first section dries the wood for combustion in the second section. In the third section, the combustion process is completed, and the ash is removed.

The York-Shipley Company has a fluidized-bed wood-waste heat-recovery system that can burn hogged wood residues with moisture contents of up to 55 percent. After the system start-up, no supplemental fuel is required to keep the wood burning, and the system is generally automatically operated. Boiler efficiencies obtained from this fluidized-bed heat-recovery unit are comparable to conventional fuel equipment.

Because of their high moisture contents, most wood and bark fuels have high heat losses due to water evaporation from the fuel. On the average, a fuel with a 50-percent moisture content requires about 13 percent of the fuel's total heat output to evaporate the moisture. Over one-quarter of the final fuel heat output is required at a moisture content of 67 percent. As the moisture content is increased, the flame temperature is lowered, and combustion is inhibited, reducing the steam output of the boiler. The wood's combustion can no longer be self-sustaining as the moisture content approaches between 64 and 69 percent. Excessively moist wood fuels would probably have to be dried prior to combustion or be burned along with supplemental fuels such as oil and coal.

The amount of excess air required for combustion of the fuel and the gas-exiting temperature determines the boiler heat loss due to dry stack gases. By reducing the amounts of excess air used and by passing the stack gases through a heat recovery unit before they exit the stack, heat losses can be minimized.

The overall efficiency of a wood burning boiler system can be calculated by evaluating these heat losses. For example, in a steam plant which burns Douglas fir bark fuel with 40-percent excess air (40-percent excess air is a normal operating condition for a representative wood-burning plant), a boiler efficiency of nearly 70 percent can be expected at stack temperatures of 400 to 500 degrees F. and moisture contents of 50 percent. These high efficiencies usually require fuel pretreatment (predrying) and stack gas heat utilization achieved by the use of heat exchangers.

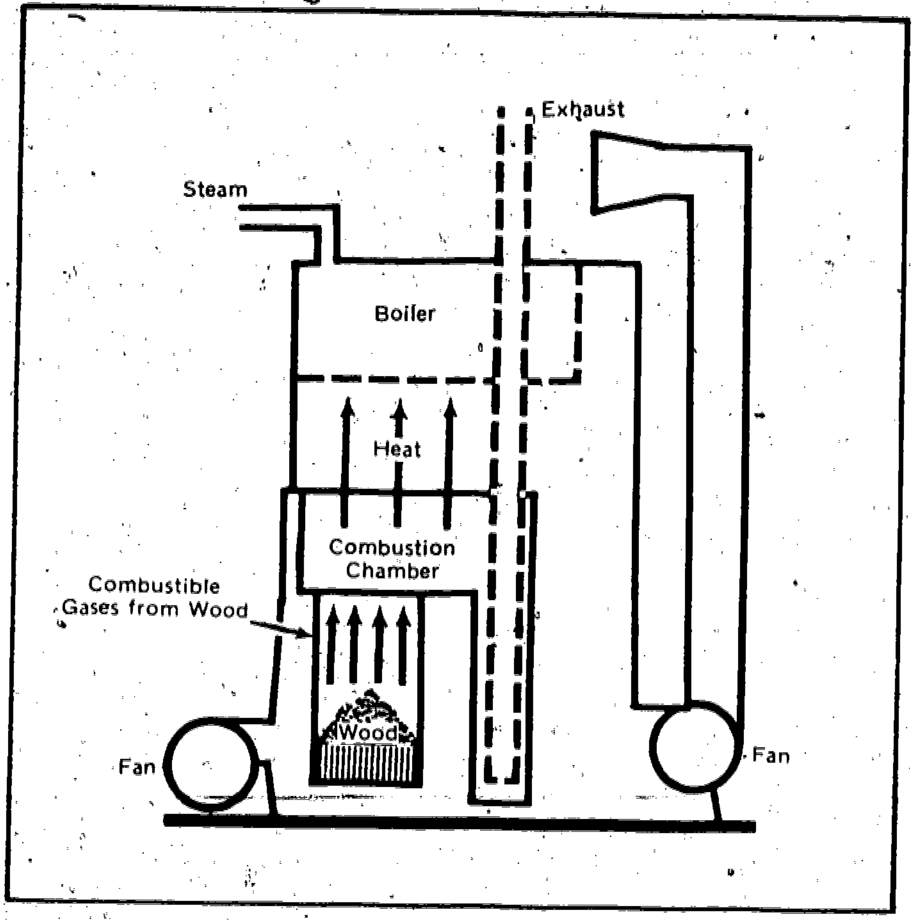


FIGURE 2

STEAM PLANT (FUEL-CELL PROCESS) FUELED BY RESIDUES FROM WOOD AND BARK

Air Pollution Control

Wood and bark fuels have relatively small amounts of sulfur and, unlike most heavy oil and coal, produce sulfur emissions in volumes which are usually well below those allowed by governmental regulations.[3] Of more concern to wood- and bark-fueled power plants are visible plume and particulate matter emission standards. Oregon's regulations for new boiler units allow 0.1 grain of particulate matter per standard cubic foot of gas. Particulate emissions from bark-fueled furnaces normally range from 0.5 to 5.0 grains per standard cubic foot.

The amount and type of particulate matter generated by wood and bark furnaces are dependent on the fuel burned. Ash contents (noncombustible portion left over after burning) vary with wood and bark type. They are generally higher in bark, which also accumulates large quantities of dirt and sand from handling operations. The emissions are comprised of dirt, sand, and char (unburned carbon). The sands and dirt are relatively large particles and are the nearly invisible component of the emissions. The char is relatively small and highly visible.

Depending on particle size, power facility size, quantities of exhaust gases, and emission rates, air pollution

TABLE 3

FUEL COST COMPARISON OF SOME INDUSTRIAL FUELS USED FOR STEAM GENERATION

Kind of Fuel	Quantity of Measure	Cost per Quantity (Dollars)	Heating Value per Quantity (Million Btu)	Assumed Steam Gen. Efficiency (Percent)	Fuel Cost ($ per Million Btu)
Oil					
No. 5 Fuel Oil	Barrel	4.80	6.3	80	0.95
~~No. 6 Fuel Oil~~	~~Barrel~~	~~4.20~~	~~6.3~~	~~80~~	~~0.83~~
Natural Gas					
Industrial Firm[1]					
100,000 therms per month	Therm	0.0661	0.1	76	0.87
500,000 therms per month	Therm	0.0612	0.1	76	0.81
Industrial Interruptible[2]					
100,000 therms per month	Therm	0.0480	0.1	76	0.63
500,000 therms per month	Therm	0.0444	0.1	76	0.58
Wood-Bark Residues					
Douglas fir sawdust	Unit[3]	2.0-4.0	16.9[4]	66[5]	0.18-0.36
Western hemlock sawdust	Unit[3]	2.0-4.0	14.3[4]	58[5]	0.24-0.48
Douglas fir hogged bark	Unit[3]	2.0-4.0	24.4[4]	67[5]	0.12-0.24
Western hemlock hogged bark	Unit[3]	2.0-4.0	19.6[4]	66[5]	0.16-0.31

Note: Cost comparisons are based on 1971 and 1972 data. All costs have risen sharply since then, but the relative comparisons are still valid.

[1] Northwest Natural Gas Co., Schedule 21, high load factor, additional charge for excess peak period usage. Effective November 14, 1971.

[2] Northwest Natural Gas Co., Schedule 23, Effective November 14, 1971.

[3] A unit is 200 cubic feet of bulk volume assumed to contain 1,900 pounds of dry Douglas fir sawdust, 1,700 of western hemlock sawdust, 2,600 of Douglas fir bark, and 2,200 pounds of dry western hemlock bark.

[4] Higher heating values per pound, dry, assumed; Douglas fir sawdust, 8,900; western hemlock sawdust, 8,400; Douglas fir bark, 9,400; and western hemlock bark, 8,900.

[5] Efficiencies assumed 40 percent excess air, 500° F. stack temperature, fuel moisture 80 percent for Douglas fir sawdust and bark and western hemlock bark, 120 percent for western hemlock sawdust.

[redacted]

FIGURE 3

COMPARISON OF THE COSTS OF SOME INDUSTRIAL FUELS USED FOR STEAM GENERATION (BASED ON DATA IN TABLE 3)

Natural gas usage was assumed to be 100,000 therms per month, and the cost of processed Douglas fir bark was assumed to be $4 per unit.

control devices to collect these particles can be installed. Larger particles can be efficiently collected by a mechanical cyclone or a series of cyclones. For smaller particles, electrostatic precipitators may be necessary to effect their removal from exiting gases.

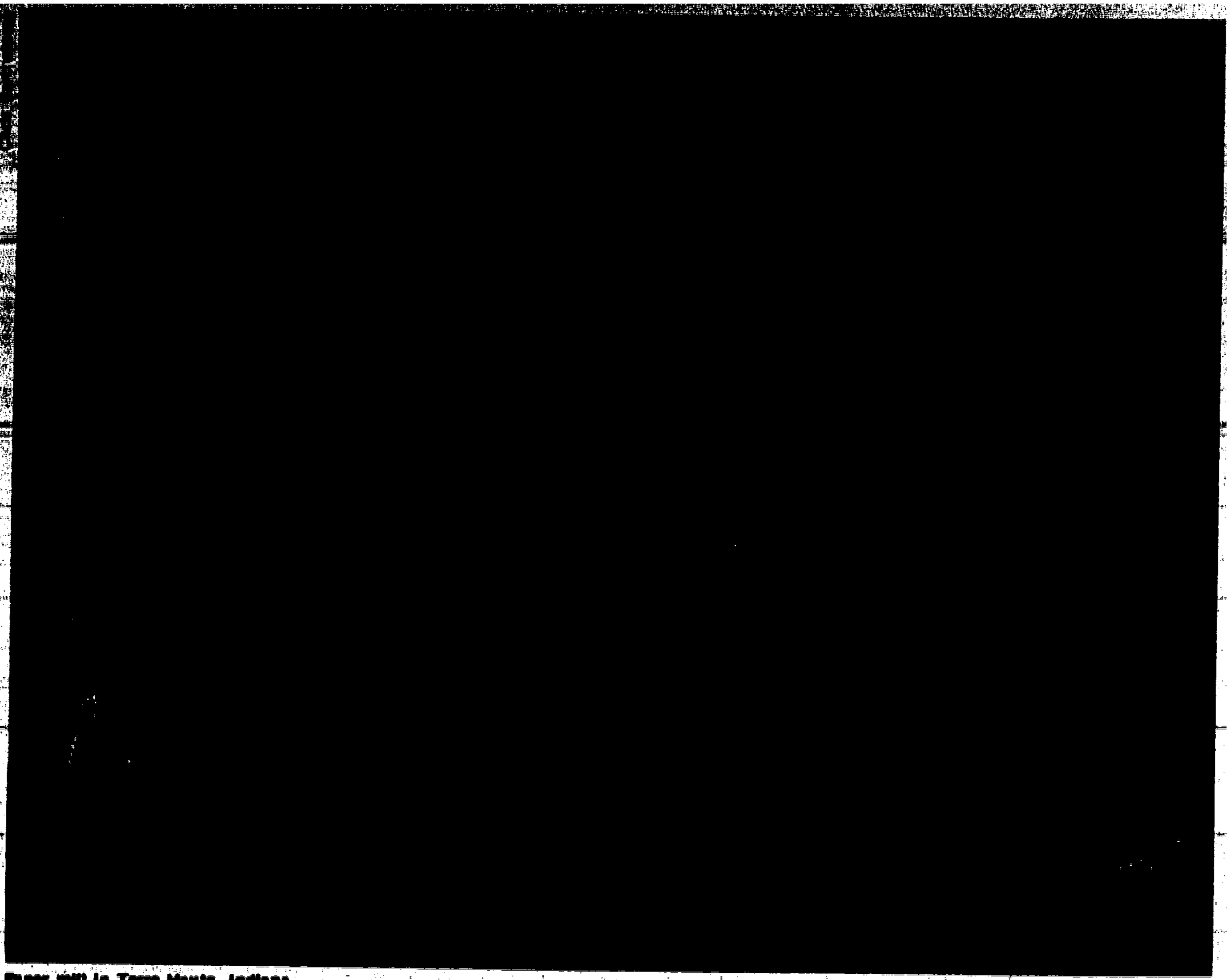
These pollution devices may require large capital and operating investments. However, depending on the char quality, the collection equipment can be cost effective. By first passing the stack gases through a screening process to remove the larger sand and dirt particles, the char can be reinjected into the furnace to complete combustion with a minimum increase in emissions.

Collection devices for wood- and bark-fueled power plants usually include a two-stage collection system. However, because there is relatively little experience with control devices for wood-fired furnaces, many collection systems are not proven. Baghouses, wet scrubbers, and electrostatic precipitators can be employed, depending upon the plant's requirements and their economic feasibility at that plant.

Wood-Waste Economics

Table 3 gives the costs for fuels with equivalent heat contents, and Figure 3 is a comparison of costs of some industrial fuels for steam generation based on data in Table 3. These statistics are based on costs for fuel in December 1972, and they show hogged-wood fuel to be considerably lower in cost than conventional fuel. Today's oil prices probably justify the increased capital and operating costs of hogged fuel utilization.

Steam plants that utilize hogged fuel usually cost more than a conventional-fuel-fired plant because of the high moisture content and handling problems of hogged fuel. Studies have shown that a boiler system burning hogged fuel alone or with a supplemental fuel would cost twice as much as a boiler that burns oil only. However, although the wood- and bark-fueled plant requires twice the initial capital investment over conventionally fueled plants, other factors should be considered, including: lower hogged-fuel costs resulting in long-term savings; fewer air pollution emissions; in-



Paper mill in Terre Haute, Indiana.

creasing conventional-fuel costs; shortages of conventional fuel; advantages of hogged fuel used with supplemental fuel;[4,5,6] and cost in otherwise disposing of wood and bark wastes.

Wood wastes can be utilized in a number of ways, and large power plant installations are not the only means of energy recovery. Logs for home use can be made from sawdust, wood chips, and other combustibles mixed with wax. Logs made from leaves have recently become a profitable enterprise; not only are the leaves effectively disposed of, but their energy is recovered. The leaves are separated, dried, and shredded before they are mixed with wax to aid combustion. They are then compressed and formed into sixteen-inch-long by four-inch-diameter logs.

All wood wastes could be treated in a similar manner to alleviate just a fraction of the energy pinch. These wastes are available all around us and are usually obtainable by the fuel processor at no cost. Sometimes the waste producer will even pay the fuel processor to remove his wastes. ☐

NOTES

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In the protoplasmic muck aeons ago, Nature learned how to tap the sun's radiant energy and re-package it into more usable energy forms—wood, coal and oil. And ever since he learned to make fire by rubbing two sticks of wood together, Man has thoughtlessly been squandering Nature's bioenergy gifts. These once-abundant carbonaceous fuels are becoming scarce, and Man must now search for renewable alternative sources to support his civilization.

At two recent meetings—one held in Florida this past January and the other in Washington, D.C. in March—the exploitation of untapped energy sources was discussed. Concepts put forward included the development of terrestrial and oceanic energy farms—the intense "harvesting" of energy through the process of photosynthesis—and the utilization of urban and industrial wastes, and agricultural and forestry residues for fuel, food and chemicals.

The bioconversion process, a two-step procedure, simply involves the creation of biomass via photosynthesis, and the subsequent transformation of this matter into gaseous/liquid/solid fuels to provide heat and electricity. Enzymatic hydrolysis, anaerobic fermentation, pyrolysis (destructive distillation) and direct combustion are the basic conversion processes for which much of the technology is already known. More exotic technologies such as biophotolysis may become feasible in the future.

According to EPA estimates, solid waste alone could supply between 1–12%, depending on the economics, of the nation's energy requirements for the near- and mid-term future, and biomass (organic matter grown for energy) has an even greater potential, perhaps making the U.S. totally independent of foreign energy sources over the long term.

The potential total energy production from biomass has been variously estimated at a conservative 3 quadrillion Btu's (quads) annually by the year 2000 and 10 quads by 2020 (ERDA's Solar Energy Definition Report, 1975), to a high of 15 quads in the year 2000 (Project Independence Report, 1974). And once the production and conversion problems are ironed out, the potential for bioconversion appears to be limited only by the public's perception of future energy alternatives.

Waste-as-fuel technologies

Theoretically, bioconversion techniques can simultaneously solve, or at least minimize, waste disposal and the attendant pollution problems while providing solid supplemental fuel, or new conversion products—liquid or gaseous fuels, sugar, protein and fertilizer. These man-designed technologies may rid cities of their burgeoning solid wastes and, at the same time, open up new sources of revenue.

The magnitude of urban waste generated annually is overwhelming. An EPA estimate places the quantity at 135 million tons/year, of which approximately 80% or the equivalent of 400 000 barrels of oil is in a form suitable for energy recovery. According to Dun & Bradstreet, the recovery of energy and materials will be the nation's number one growth industry in the last quarter of this century.

Waste-as-fuel technologies are available for the prudent utilization of those commodities now thrown away. For example, waterwall incineration is being used in the Chicago Northwest Incinerator, modeled after the Martin incineration system widely used in Europe; in the Saugus, Mass., refuse-energy plant soon to be completed; and in the fully operating Nashville, Tenn., thermal transfer unit.

Another technology—prepared waste as supplementary fuel for co-firing with coal or oil—has been successfully demonstrated at the St. Louis/Union Electric plant (see *ES&T,* May 1976, p 430), a project that is soon to be expanded into a profit-making commercial venture. And this very same technology is spreading to Ames, Iowa, and Chicago, Ill. A variant method—solid waste co-combusted with sewage sludge—is being tested, under EPA funding, at the St. Paul/Seneca Treatment Plant Sludge Incinerator. And the investigation of fluidized-bed combustion, again under EPA sponsorship, is now underway.

Another physical process, pyrolysis, the destructive distillation of wastes to produce gases, oils and char for use as boiler, residential-heating and motor fuels, is being demonstrated in Baltimore, Md. (see *ES&T,* February 1975, p 98), Charleston, W.Va., and San Diego, Calif.

Slow but sure

Biological processes available to convert solid wastes to useful products in[illegible]de fermentation and enzymatic hydrolysis. Anaerobic digestion can transform organic solid wastes to methane-ontaining gases. Under an ERDA con-act, design and construction plans for igesting 50–100 tons/day of municipal olid wastes are being drawn up by Waste anagement, Inc. at its Pompano Beach, Fla., facility. The Institute of Gas Technology (IGT) has built a 400-liter digester at its Chicago facility that is being used to demonstrate the feasibility of accomplishing biogasification of municipal solid waste and sewage solids to a methane-rich product gas. IGT's project is at the pilot-plant stage.

A bench-scale effort at the Dept. of the Army's Natick (Mass.) Laboratory is, with EPA support, being conducted to demonstrate the feasibility of enzymatic hydrolysis of the cellulosic materials found in the urban waste stream (see *ES&T,* November 1975, p 1011). Here, the conversion product is glucose, which can be further manipulated to a single-cell protein or ethyl alcohol.

Certain industries, sugar refining and paper products, for example, are reusing, albeit in an altered form, their formerly discarded wastes as a means of reducing both their pollution problems and their dependence on externally obtained fuels.

In pursuit of Btu's

Preliminary studies are underway to estimate the quantities of forest, field crop and animal wastes potentially available for bioconversion. Institutional, technical, economic and environmental variables associated with the large-scale conversion of these residues to fuels, fertilizers and chemicals are also being delineated.

To minimize their disposal headaches, lumber companies are using most of the slash and mill residues that they formerly discarded to heat and power their mill operations. These companies are even studying the economics and ecology of [illegible] there are [illegible] to be able to use these "wastes" as fuel directly or as the feedstock for other fuels and [illegible]

The bioconversion of animal wastes by using small-scale, on-site digesters to produce methane gas for cooking and lighting, and a nutrient-rich residue that can be used as a feed supplement for ruminant animals [illegible] technology being considered for farms in the U.S.

Elsewhere in the world, a cow-dung biogas plant, the Gobar Gas Plant, was built in India in 1939. Today, India is considering the installation of 100 000 of these farm-size digesters. China already has about 500 000 in operation, and Korea is installing 50 000.

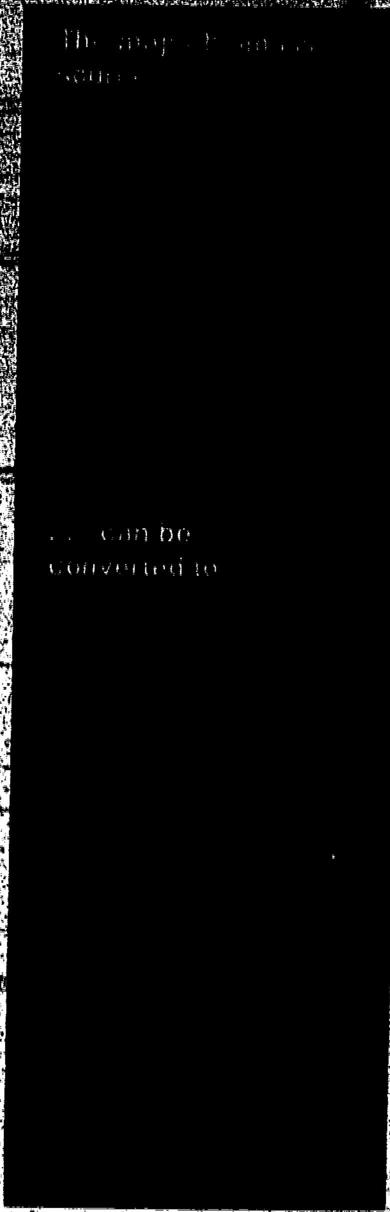
Energy farming

One side of the bioconversion coin, the better utilization of civilization's wastes, would add only incrementally to near- and mid-term energy supplies. The flip side of the coin, energy from biomass, would offer the most significant future source of fuels. An intentional increase in the worldwide rate of carbon fixation could be achieved through the establishment of land and open-ocean farms. The intense cultivation of rapidly growing plants and trees such as canes and conifers, adjunctive to existing agricultural and forestry operations or as de novo energy-farming enterprises, could serve as energy feedstocks. Frequently harvested, this biomass could be converted to fuels, sugars and proteins.

Fresh water environments could also be used for the aquaculture of algae and the nefarious water hyacinth. NASA has shown that the hyacinth, once thought only to be a fouler of water ways, is able to "digest" sewage and can thus help clean up sewage lagoons. Harvested, dried and ground into meal, these plants can be blended into corn silage and fed to cattle. Alternatively, the harvested hyacinths can be converted, via fermentation, to methane gas. The hyacinth, now man's bane, may yet turn into a booming industry.

Large floating artificial meshes or rafts of plastic lines have been used as the "land" on which marine life forms have been grown. The rapidly growing giant California kelp, sargassum and plankton have been shown to be suitable feedstock for the production of methane gas, fertilizers, chemicals, and food.

Although the ability to grow biomass for energy has been proven, the economics of energy farming—both the direct and indirect costs—still need to be carefully worked out. And although major environmental benefits may accrue from the use of biomass as the energy source in lieu of the traditional hydrocarbon fuels, studies are needed to assure that adverse effects are not inadvertently introduced.



The problems, benefits

Some potentially grave problems, whose resolutions may be difficult if not impossible, can even now be surmised. For example, the reflectivity over huge areas of the earth's surface may be altered by rapidly growing plants raised for biomass. To fertilize the surface-floating ocean farms, the nutrient-rich waters of the cold ocean depths could be pumped to the surface. Will world weather modifications occur as a direct result of altered temperature and reflectivity over enormous terrestrial and oceanic areas specifically dedicated to energy farming?

If large land masses are devoted to single crop horticulture, will the absorption of moisture in these areas be modified with accompanying loss of nutrient-rich soil and increased water pollution? What happens to the established ecological structure in areas where single-crop farming is introduced? If plants formerly used for ground cover are now harvested for bioconversion, will soil erosion be accelerated?

To profitably establish ocean farms, huge areas of the marine environment will have to be utilized. Is this the best use of the world's oceans? Even more touchy, can international cooperation on such a massive scale be achieved?

On the benefits side, the use of wastes and biomass grown especially for energy most definitely reduces air, water and land pollution. If prime land is set aside for the growth of edible crops and lumber for shelter and other essential purposes, then energy crops will have to be grown on marginal or infertile land. The concomitant benefit is then reclamation of exhausted or eroded lands. It is even possible that, with prudent planning, the development of energy farms will have the salubrious effect of stabilizing global weather patterns.

Certainly, bioconversion technologies offer the assurance of future fuel, food and chemical supplies. For the U.S. and other highly industrialized countries, it reduces both the petroleum leverage the OPEC nations now enjoy, and the hazards associated with advanced coal and nuclear technologies—especially the dispersion of fissionable materials. For the Third-World countries, bioconversion offers small farms and villages self-sufficiency and an improvement in the quality of life.

A bright sunny future

Public awareness of the potential hazards inherent in nuclear energy technologies is resulting in, if not a gigantic groundswell against, at least a steadily growing opposition to this form of energy production. Advanced coal technologies, while they permit the expanded use of the nation's vast coal reserves, carry with them some potentially serious adverse environmental and occupational impacts. Conservation measures alone, even if the U.S. public could be convinced of their need, cannot solve the country's energy problems. In addition, the search for better insulation materials and the construction of better insulated buildings with recirculating air systems can result in occupational and indoor air pollution hazards.

And so, with the problems attending the increased utilization of coal, the inherent limitations and potential problems of conservation efforts and the very real possibility of a non-nuclear future, the U.S. may yet witness the enhanced utilization of biomass for energy. The caveat, of course, is that the social, economic, institutional, environmental and remaining technical problems can be ironed out. At its brightest, bioconversion offers secure, renewable and clean sources of hydrocarbons for Man's manipulative purposes.

LRE

Scientists are finding ways to redirect photosynthesis—the fundamental source of food—to produce hydrogen, the fuel of the future.

GREEN PLANTS MIGHT PROVIDE

by Gene Bylinsky

Billions of years ago, nature evolved a marvelous energy-producing process by which green plants use the pigment chlorophyll to transform sunlight into stored foodstuff—mainly starches and sugars. Today some scientists believe that our best hope for achieving long-term energy independence lies in redirecting this grand process of nature, photosynthesis, toward the production of fuel—specifically, hydrogen. Sunlight would be employed to extract hydrogen gas from ordinary water. The hydrogen, in turn, would be used in gaseous form as a substitute for natural gas or in liquefied form as a substitute for gasoline.

The vision is no pipe dream. In a number of laboratories, scientists have been demonstrating that it is possible to generate hydrogen by utilizing water, sunlight, and portions of green plants. This encouraging news is stimulating some optimists to predict that small commercial devices for converting sunlight and water into hydrogen will be performing auxiliary jobs five or ten years from now—harbingers of big hydrogen-producing installations in the years beyond.

The harnessing of sunlight for photochemical production of hydrogen would represent a significant advance in sophistication over the more familiar techniques of trapping the sun's energy with solar panels to heat or cool buildings or to generate electricity with photovoltaic cells. Sunlight-harvesting systems utilizing photosynthesis or similar processes would need no expensive mirrors to focus the light, but would soak it up directly. Their cost-efficiency could be much greater than that attained through conversion of light into heat or electricity by means of artificial solar cells.

Besides, hydrogen as an end product offers obvious advantages over heat or electricity. Hydrogen can be stored for later use. It can be transported by pipeline over long distances at one-eighth the operating cost of sending electricity through high-voltage cables. It is an exceedingly clean-burning substance—the only residue would be water. In liquid form, moreover, hydrogen packs about two and a half times as much energy as gasoline by weight. (See "The Coming Hydrogen Economy," FORTUNE, November, 1972.)

A transition to reliance on hydrogen as a major fuel could not be made overnight, of course. It would require costly modifications in distribution lines, storage facilities, pumping stations, household appliances, internal-combustion engines, and so forth. And going from relatively tiny amounts of hydrogen produced in laboratories to the enormous quantities that would begin to make an economic impact—billions of cubic feet a day—would demand huge capital outlays and the solution of engineering problems that haven't even been faced yet. But the idea of relying on a potentially limitless source of energy no foreign potentate could interfere with has immense appeal. Using sunlight to produce hydrogen, furthermore, would make a lot more sense than using nuclear or fossil-fuel power plants for that purpose and consuming one form of energy in the making of another.

Man has known for a century how to extract hydrogen from water by means of electrolysis, the passage of an electric current through water. But that is a relatively inefficient process. More recent are various catalytic steam and partial-combustion processes in which natural gas, oil, or coal are broken down to yield hydrogen. These processes are hardly an improvement over electrolysis, since they consume our dwindling fossil fuels. The matchless advantage of the photosynthetic approach is that, as one scientist puts it, "the sun pays the energy bill."

Skipping over millions of years

The idea of using sunlight to generate hydrogen still seems strange even to some scientists. After the National Science Foundation in 1973 brought together specialists from different fields in a workshop on biophotolysis, or the biological "splitting" of water, its report said: "For many attendants, the subject was rather new; for some, to the point of surprise."

But a few specialists in the field have known for more than a decade now that hydrogen can be produced in systems utilizing the green plant's photosynthetic apparatus. The familiar fossil fuels—oil, coal, natural gas—are end results of photosynthetic reactions that occurred eons ago. The objective of the new research is to skip over millions of years and go directly to fuel production.

Plants do not produce hydrogen in a usable form. They extract hydrogen from water not as a gas but as ions, or protons, which enter into the complex processes that

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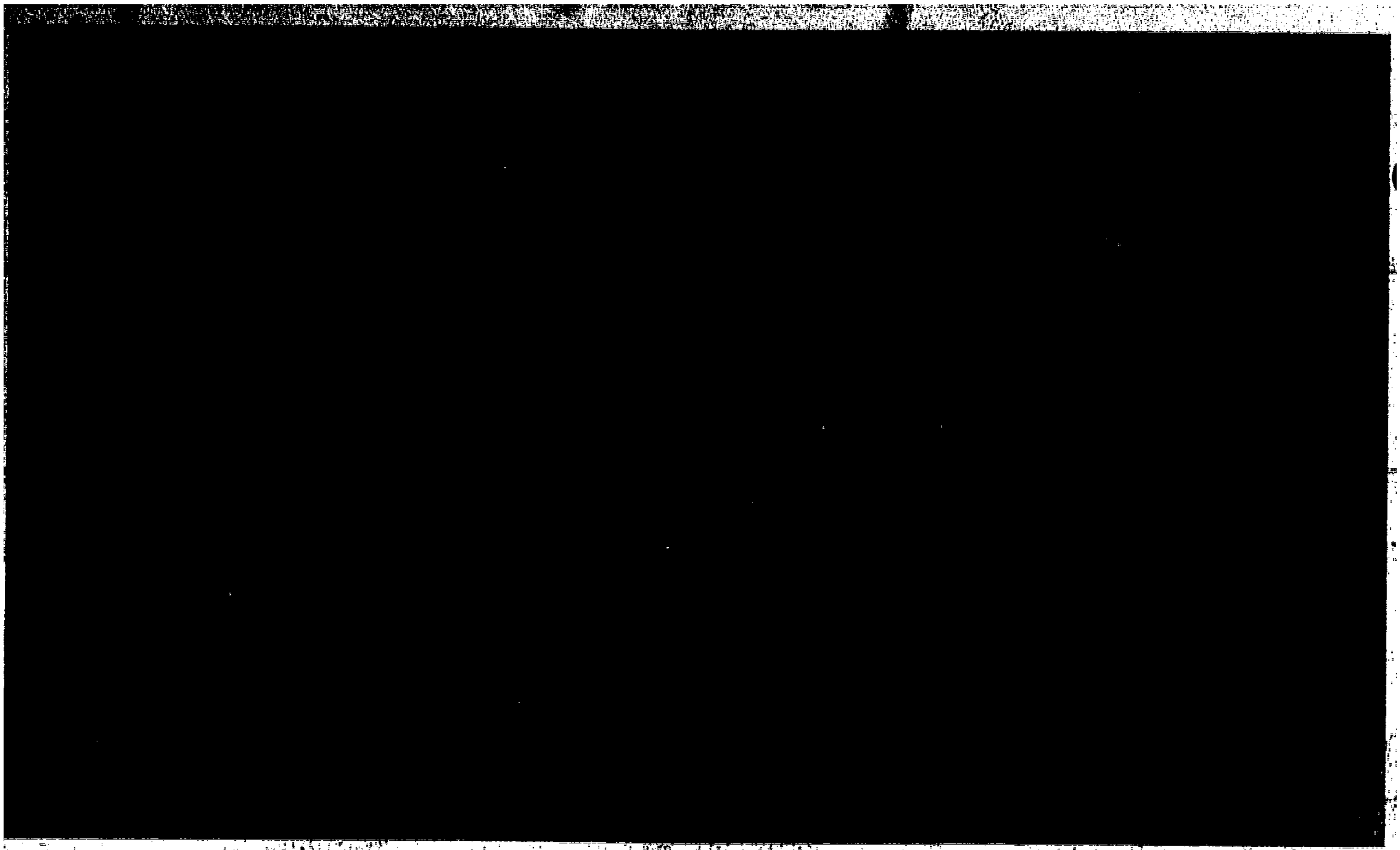
Research associate Peter J. Schuyten

THE CHEAPEST ENERGY OF ALL

Splitting water with sunlight was a notable scientific achievement, though green plants do it all the time. In this setup, mirrors direct sunlight onto the glass vessel, which holds glass slides covered with a layer of a chemical complex, only one molecule thick. The complex, which contains the light-sensitive metallic element ruthenium, absorbs light, becomes activated, and cleaves water into gaseous hydrogen and oxygen. Bubbles of these gases rise to the surface and are collected. This method of producing hydrogen was discovered by the scientists whose faces are reflected in the mirrors: chemists Hertha and Gerhard Sprintschnik, an Austrian couple working at the University of North Carolina. Their simple system produces hydrogen only in thimbleful quantities, but the Sprintschniks believe it may become a forerunner of large solar-powered hydrogen generators.



Getting Nature to Make Fuel Instead of Food

These diagrams sum up schematically how the natural process of photosynthesis works and how it is being redirected toward production of fuel. The chloroplast is a chlorophyll-containing structure within the plant cell—chlorophyll, of course, being that ubiquitous green pigment of the plant world. At the heart of the chloroplast is the "reaction center," consisting of a single molecule.

When a photon, or quantum, of light impacts a reaction center, it sets in motion a series of events that within five minutes or so lead to the synthesis of carbohydrate (diagram at left). The photon's energy is almost instantaneously transferred to an electron, which is knocked out of the reaction center and taken up by a neighboring "acceptor" molecule, which carries the electron away. The reaction-center molecule reaches out for the nearest available "donor" to replace the lost electron. This donor is water, brought up through the roots and present in the plant tissues. The chemical bond between oxygen and hydrogen in the water molecule is very strong, and sunlight in the visible range that green plants utilize isn't powerful enough to break this bond directly. But sunlight accomplishes the same purpose in a more subtle way, by inducing the reaction-center molecule to extract electrons from water.

Water is thus "split" into hydrogen ions (protons), electrons, and molecular oxygen, which diffuses into the air. The electrons and hydrogen ions are passed along from one molecular carrier to another, combined into a strongly reactive compound, and finally employed—along with carbon dioxide taken from the air—in the manufacture of glucose, a simple carbohydrate.

Scientists are now engaged in redirecting this process toward generation of hydrogen gas (diagram at right). To produce hydrogen, they introduce the enzyme hydrogenase, extracted from photosynthetic bacteria or from algae. Scientists don't know exactly how hydrogenase works, but somehow it induces the electrons and hydrogen ions extracted from water to link up and form hydrogen gas. Another promising approach being pursued is to recreate the bare essentials of the photosynthetic apparatus with synthetic chemicals that mimic the abilities of chlorophyll and hydrogenase to generate hydrogen.

restructure hydrogen and carbon dioxide into carbohydrates. (See diagram, opposite.)

Fortunately, however, there are some photosynthetic microorganisms that do yield measurable amounts of hydrogen gas under special conditions. These organisms include certain algae that release hydrogen in an apparent process of priming their photosynthetic apparatus. They do so with the aid of an enzyme called hydrogenase, which induces electrons to link up with hydrogen ions extracted from water. This linking-up restructures the particles into hydrogen gas.

In 1961 a brilliant pioneer in photosynthesis research, Daniel I. Arnon of the University of California's Berkeley campus, showed how to get around the reluctance of higher plants to yield hydrogen. He coupled chlorophyll-containing chloroplasts, which he extracted from spinach leaves, to a bacterial hydrogenase, shined a lamp on the mixture, and produced some hydrogen. Putting these ingredients—chlorophyll and hydrogenase—together is the dominant approach now being pursued in a number of university, government, and corporate laboratories in this newest search for sources of energy.

There is much to be learned. While photosynthesis has been studied for nearly 200 years, the attempts to rechannel parts of the photosynthetic machinery toward production of hydrogen are only a few years old. Even Arnon's experiment was aimed at illuminating the process of photosynthesis rather than at potential production of energy. Arnon, furthermore, had used organic material rather than water as the source of hydrogen ions. Proof was still needed that sunlight could split ordinary water outside a living plant.

It took the energy crisis to send scientists scurrying into their labs to start looking at photochemical hydrogen production in earnest. Almost simultaneously in the early 1970's, work began in about a dozen major labs. At least three corporations, Martin-Marietta, General Electric, and Exxon, also got into the act.

Coping with life's instabilities

In 1973 a group at the University of California's San Diego campus successfully used water as the source of hydrogen. Hydrogenase blocked the path leading to carbohydrate synthesis, and for about fifteen minutes the chloroplast-hydrogenase system generated a minute amount of hydrogen gas from water.

This achievement galvanized researchers at other labs. Recalls microbiologist Lester O. Krampitz of Case Western Reserve University: "When we first began, we jumped for joy when we began to measure hydrogen being produced—even if it was just a blip—because we knew we were on the way."

But as researchers strove to improve techniques and extend operating time, they ran into tough obstacles. Lack of stability plagues any biological subsystem taken out of its normal setting. Chloroplasts and hydrogenase are not exceptions. Chloroplasts deteriorate outside a plant cell in about half an hour; some varieties of hydrogenase can be inactivated by oxygen in a few minutes.

Researchers, then, had to find ways to protect chloroplasts and hydrogenase from swift deterioration. [illegible] effective technique has been to encapsulate chlorophyll reaction centers inside microscopic plastic beads. The plastic acts as a semipermeable membrane, permitting small molecules, such as those of hydrogen or oxygen gas, to pass through, but not large molecules of more complex substances that might damage the chloroplasts. When the beads, floating on water in a test tube, were illuminated with a lamp, they produced tiny amounts of hydrogen for a week at a time. Other scientists have succeeded in extending the life of hydrogenase from minutes to more than a month by binding molecules of the enzyme to the surface of small glass beads and keeping them in a favorable chemical environment.

So far the efficiencies of the hydrogen-producing systems are generally low—only about one-tenth the efficiency of isolated chlorophyll producing carbohydrate. But this represents a hundredfold improvement over results obtained only three years ago.

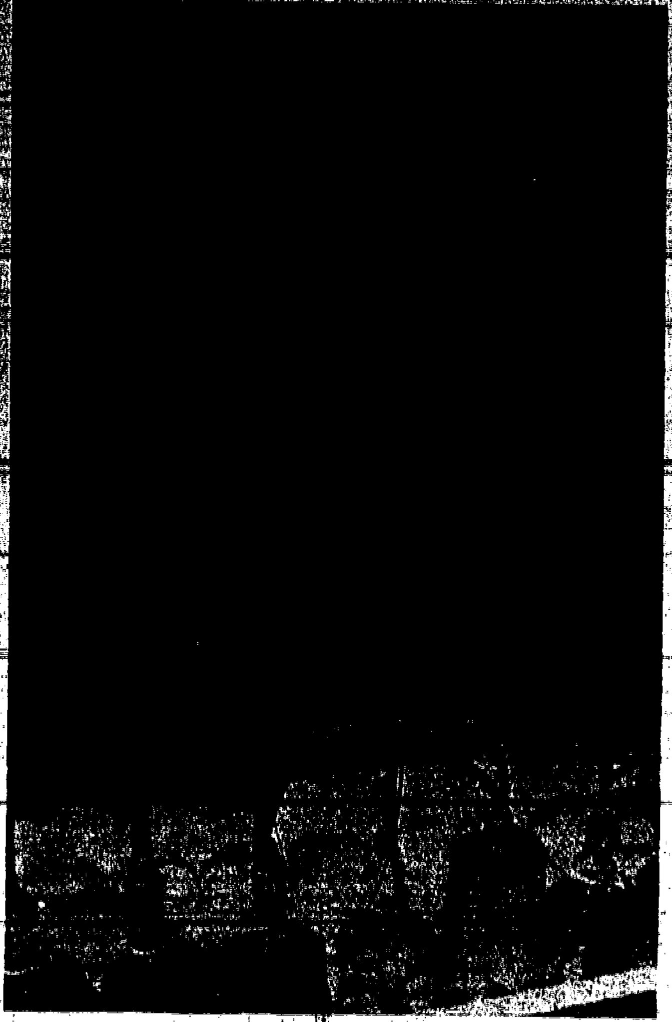
The blue-green and purple approaches

Following other paths to photosynthetic production of hydrogen, some scientists are employing microscopic algae and bacteria. A particularly promising system, devised at the Richmond field station of the University of California, utilizes blue-green algae. These tiny plants have *both* chlorophyll and hydrogenase. They manage to exclude oxygen from some of their reactions almost completely—a big advantage over the coupled chlorophyll-hydrogenase systems, where oxygen can poison both chlorophyll and hydrogenase. The Richmond apparatus recently yielded two liters of hydrogen gas during a continuous twenty-day-long run—a record for a biological system so far. That, of course, isn't a great deal of hydrogen—it would be just enough to keep a pilot light on a gas stove burning for nine minutes. But the California scientists are confident of eventual success. They are now operating a prototype outdoor generator that is powered entirely by sunlight.

Still another microscopic organism has recently attracted attention from scientists interested in hydrogen production. This is a purple-colored bacterium that lives in salt flats. It uses, not chlorophyll, but a pigment closely related to rhodopsin, the pigment in the eyes of animals that converts light into electrical signals to the brain. Like chlorophyll, the pigment in the purple bacterium absorbs photons of light. But while chlorophyll turns the energy of photons mainly into a stream of electrons, the purple-pigment molecule produces a stream of protons. When impacted by a photon of light, the molecule ejects a proton into the surrounding salty fluid and takes up another proton from the fluid, gaining energy from this flow of protons. Since the protons are electrically charged, the purple bacterium in effect converts solar energy into electrical energy. Its simplicity of operation is of great interest to scientists investigating biological solar-energy conversion. One group is already working on a system in which electricity produced by the bacterium would be used to split water into hydrogen and oxygen.

In many ways, the ideal approach to photochemical production of hydrogen would be to use entirely synthetic components. Among other things, this would improve the efficiency of the system. Plants use only about half of available sunlight, but from the standpoint of hydrogen production, it would be desirable to utilize the full range and intensity of sunlight.

For these reasons and others, wholly synthetic systems are emerging as a strong contender. Melvin Calvin, the Berkeley biochemist who in 1961 won the Nobel prize for tracing the pathways of carbon in photosynthesis, is perhaps the leading adherent of all-synthetic schemes. Starting a few years ago, Calvin and his associates have been trying to synthesize dyes that would imitate chlorophyll's light-absorbing and water-cleaving ability, and artificial catalysts that would imitate the action of hydrogenase in the production of hydrogen. "My approach," says Calvin, "has been to build synthetic devices based on information from green plants, but without their variables."



Many paths to hydrogen production are being investigated these days. University of California biochemist John R. Benemann (right) and Leon Kochian, an undergraduate, are doing research on the ability of microscopic blue-green algae to produce hydrogen under special conditions. The algae normally draw nitrogen from the air for their metabolic needs, but when deprived of atmospheric nitrogen they switch to an alternative [illegible] that involves emission of hydrogen. At the Richmond, California, [illegible] station, scientists grow the algae in an argon atmosphere under artificial light imitating sunlight. The argon is pumped through all that tubing in front of the two scientists. In a recent experiment that ran continuously for twenty days, the apparatus shown here generated two liters of hydrogen, a record for such systems. The scientists have begun testing a prototype of a hydrogen generator powered by sunlight.

An accident in North Carolina

In this task the Calvin team was recently outdistanced by a young couple working at the University of North Carolina. Gerhard and Hertha Sprintschnik, both chemists from Austria, succeeded, for the first time, in using sunlight to split water, with an artificial chemical compound taking the place of chlorophyll and hydrogenase.

The experiment contained all the ingredients of a classical scientific discovery. It was made by accident, with rather primitive equipment. The two scientists, working without even laboratory assistants to help them, had only the counsel of their senior adviser, Professor David G. Whitten. They weren't seeking to produce hydrogen from water. Instead, they were investigating the properties of membranes, which have a critical bearing on health and disease. (The project was being sponsored bv the National Institutes of Health.)

The Sprintschniks were working with the metallic element ruthenium. When dissolved in water and illuminated, a ruthenium powder fluoresces bright red, giving off absorbed light. One day last December, Gerhard Sprintschnik submerged a slide covered with a very thin layer of an insoluble ruthenium complex in water and shined a light on it. He did not see any fluorescence. This unplanned experiment was the key one, for it meant that something else was happening to the light energy. Perhaps it was interacting with water.

At first, however, the Sprintschniks didn't detect any splitting of water. But when Gerhard came into the lab last Christmas Day, he saw bubbles rising to the surface from the slides he had put into a vessel full of water the previous day. The Sprintschniks had to be certain, though, that what they were seeing was a true cleaving of water by light and not some secondary effect. A ratio of two molecules of hydrogen to one of oxygen would prove that water molecules were indeed being split. The young scientists collected a sample of the gas and then had to wait impatiently for about a week before it was analyzed. It proved to consist of molecular hydrogen and oxygen in just about the proper ratio.

Knowledge deferred

Many problems remain to be worked out before the Sprintschniks' system of producing hydrogen can be scaled up. For one thing, ruthenium, at about $3,500 a kilogram, is approximately as expensive as gold. But a little bit goes a long way: the Sprintschniks have calculated that in a monolayer (a layer one molecule thick), a complex containing a kilogram of ruthenium could cover forty acres. If the stuff could be made to stay in place, it probably would last indefinitely.

The two scientists envision the eventual emergence of large hydrogen converters in which a ruthenium complex, or a similar synthetic material mimicking chlorophyll, would be spread thinly on glass plates or sheets of plastic to soak up sunlight. Hydrogen and oxygen would be collected inside translucent plastic canopies covering the installation. It would be necessary to separate the two gases, because together they pose a threat of explosion. The oxygen could be compressed for use in industrial operations; the hydrogen would be fed into pipelines.

The Sprintschniks' success is spurring on a variety of photochemical approaches to hydrogen production. Exxon is developing an experimental photoelectrochemical cell that sunlight can energize into producing hydrogen. At New Mexico State University, scientists have devised a copper-containing compound that can use ultraviolet light to produce hydrogen.

All these systems, whether wholly or partially synthetic, might benefit from additional basic knowledge of exactly how a green plant converts sunlight into chemical energy so efficiently in the primary step, how it extracts hydrogen from water, and how hydrogenase turns the hydrogen ions into hydrogen gas. Many gaps in basic understanding still exist, partly because the light portion of the process takes place in millionths, even billionths, of a second. Such events can be traced only with highly advanced, and extremely expensive, instruments.

Whether and how soon the promise of using sunlight to produce hydrogen will be realized will depend in part on the funding of research efforts. It appears that the Energy Research and Development Administration, the largest source of energy-research funds, has yet to perceive the full potentialities of photochemical production of hydrogen. This year the agency will spend $3 million, a barely perceptible fraction of its $6.4-billion budget, on photosynthesis-related research. This failure of federal energy planners to get behind photochemical research may be their biggest oversight of all. END

The recipe calls for spinach in some of the hydrogen-generation experiments of biochemists Lester Packer (left) and Elisha Tel-Or at the University of California's Berkeley campus. Vials containing the reaction mixture of chlorophyll, extracted from spinach leaves, and enzymes from bacteria and algae are kept free of oxygen to delay deterioration of the substances. The vials are immersed in water and illuminated from below by a bank of 50-watt reflector lamps, which imitate sunlight. The red plastic sheet filters extraneous light from other sources in the laboratory. The researchers monitor the reaction by periodically withdrawing samples of hydrogen and testing them in a gas chromatograph. Test results emerge as a graph on that moving strip of paper in the background.

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Not out of the Woods

The world's biggest fireplace?

BY CHARLES E. CALEF

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AS SUPPLIES OF FOSSIL fuels diminish at an accelerating rate, it is natural to consider replacing them with energy from the sun. One solar technology which is attracting interest is the oldest of all: harvesting and burning plant tissues or combustible liquids synthesized from them, a process called bioconversion. There is a pervasive feeling in this country, summed up by the bumper-sticker exhortation to "split wood, not atoms," that bioconversion is a desirable, clean, and renewable source of energy which we might be able to fall back on when our present fuels become unavailable. This feeling has manifested itself in several ways: Studies have been made of the potential of New England's forests to supply energy for the Northeast.[1,2] At an American Chemical Society seminar in early 1976 on "viable alternate energy sources" the Inter Technology Corporation described its plans for plantations to fuel military bases. During the energy crisis of the winter of 1973, state and national forests were opened to individuals wishing to cut firewood; state forests in New York are still open for such purposes upon payment of a small fee. And woodburning stoves are enjoying a comeback.

The idea of returning to large-scale burning of wood products for energy might at first seem retrogressive, but proponents point to its many attractive features:

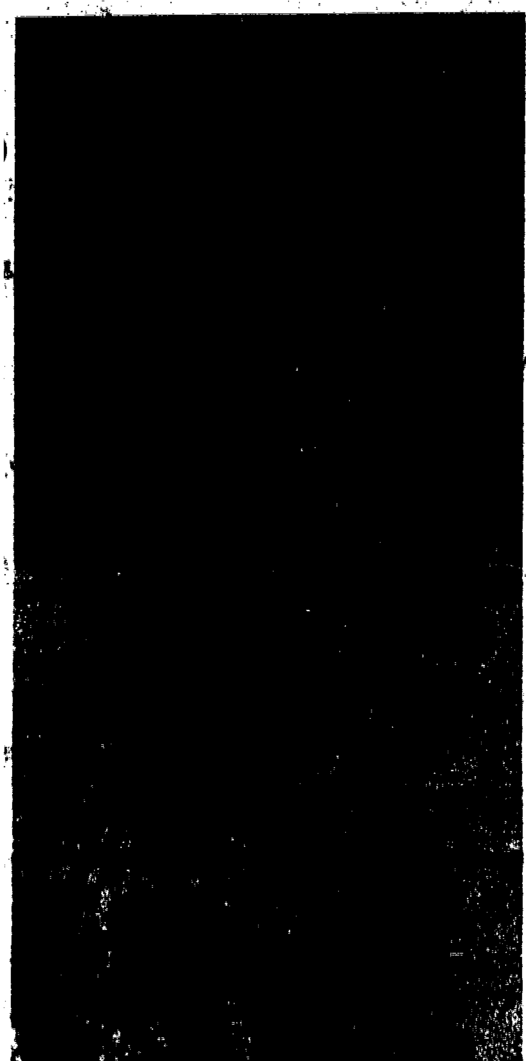
1. It is a solar technology, depending only upon the inexhaustible radiant energy from the sun.

2. Unlike most other solar technologies, it is proven. The photosynthetic apparatus of the green plant cell has evolved over hundreds of millions of years into an extraordinarily complex and efficient converter of sunlight into energy stored in chemical bonds of carbohydrate molecules.

3. The energy source of the technology — the growing plant — does not require large quantities of exotic, rare, and sometimes toxic materials as do more sophisticated man-made solar-conversion contrivances.

4. Green plants obviously are self-replenishing and biodegradable. It is claimed that when plants are burned they produce relatively little air pollution.

Given the considerable advantages of this technology, there is a tendency to overlook its shortcomings. First, the present worldwide


U.S. Forest Service

Naturally growing forests have been considered as a source for biomass conversion.

use of energy is so staggeringly huge that it is inconceivable that bioconversion can supply more than a tiny fraction of the total. Its contribution will be limited by the lack of some very basic resources: land, water, and nutrients. Second, even a moderate application of the process may damage valuable biotic communities and other natural resources, especially soils.

The Energy Plantation

There are two existing general approaches to acquiring biomass, or living material, for conversion: Naturally growing biomass, as in forests, can be harvested; in states such as Maine and Vermont, which have low populations and large forests, it has been suggested that naturally growing biomass be exploited for fuel. Similarly, by-products such as stalks, chaff, and animal droppings have been considered suitable for conversion to fuel for energy. The other suggested approach is to create special energy farms where a crop selected for its high production level is used as a fuel or feedstock rather than as a food. This alternative – the energy plantation – is thought to have greater potential because controlled species composition, soil nutrition, moisture content, and planting and harvesting times should provide for much higher levels of productivity than would occur naturally. The Stanford Research Institute has described one hypothetical energy plantation as follows:[3]

"A biomass plantation would be relatively large in terms of conventional agriculture, covering perhaps an area fifteen miles square (144,000 acres). A facility for converting the biomass to usable energy (e.g. [a 60-megawatt] electric power plant or gasification plant) would be located at the center of the plantation. The biomass crop would consist of a conglomerate of species selected primarily on the basis of high biomass yield. . . . Conventional farming practices would be used where appropriate or modified to exploit either production potential or energy-costs savings to the fullest extent possible. Examples of such modifications would be the use of 'no-till' methods, the harvest of roots and crowns in addition to aerial plant parts (annual crops), and the use of understory . . . crops. Yields of 30 tons of dry biomass per acre-year would be anticipated, providing an annual energy harvest of 450 million Btu per acre.

"The plantation operation ideally would produce three crops of annuals per year. . . . Before planting, the fields would be cleared of weeds by the application of an herbicide to eliminate competition for water and plant nutrients. Planting the biomass crop could be combined in one operation with the application of fertilizer. At an appropriate interval after planting, a side-dressing of fertilizer would be applied. The biomass crop would be harvested by means of self-propelled combines, which would chop the biomass into small pieces to facilitate drying. . . . Aircraft would apply insecticides and fungicides when and where needed. It is assumed that an average of two such operations per acre-year would be needed across the entire plantation. In certain instances it would be feasible to apply these pesticides with the irrigation water. . . . Irrigation water would be applied at two-week intervals. . . . The plantation would be operated seven days per week, 12 hours per day. Irrigation activities would be performed 24 hours per day."

The U.S. Energy System

The U.S. acquires energy principally from fossil fuels, with minor contributions from hydropower and nuclear sources. Of the 72.16-quadrillion Btu consumed in the U.S. in 1972, 56.5 quadrillion Btu, or 78 percent of the total, went to end uses such as heating and cooling buildings, making steel, fueling vehicles, and so on. Of the 22 percent lost in various transportation and processing steps, 18 percent was heat wasted in the generation of electricity.[4]

Of particular interest here is the magnitude of the energy utilization, which is impossible to conceptualize unless it is expressed in terms within our experience. We can accomplish this and, at the same time, gain an understanding of bioconversion's potential contribution to the nation's energy supply by determining the amount of resources which would be needed to supply this amount of energy by photosynthesis.

Plants, by absorbing the radiant energy of the sun and using it to drive chemical syntheses, build up a store of organic compounds in plant tissue or biomass. The energy which is released by the combustion of these compounds, usually expressed as kilogram calories (Kcal), is called net primary production. The rate of net primary production depends on the types of plant species and the hospitality of the environment. Productivity rates also are expressed in terms of weight, such as 30 tons per acre-year. Some net primary production rates are listed three different ways in Table 1.

- *Land Requirement.* Table 1 shows that 1,540 Kcal per square meter is the net productivity of the cool temperate forest, the type of forest which grows in New England and has been cited as a possible source of energy for Maine and Vermont. At this rate, how much land would be required to produce the 72.16 quadrillion Btu, or 18.18 quadrillion Kcal, used annually in this country? The equation

$$\frac{18.18 \text{ quadrillion Kcal}}{1{,}540 \text{ Kcal per sq. meter per year}} = 11.8 \text{ trillion sq. meters per year}$$

indicates a land requirement of 2.92 billion acres, or 4.56 million square miles – an area larger than the continental U.S., which is roughly 3.68 million square miles. Obviously, this type of forest could not produce as much energy as is now being consumed in the U.S. The situation is hardly more auspicious for the more productive plants in Table 1. Each of the plants would require huge land areas to supply all of our energy needs, as can be seen in Table 2. Even sugar cane, one of the most productive of all plants, would have to be intensively grown over 148 million acres, or 6 percent of the total U.S. land surface area – an area only a little smaller than Texas – to provide the annual energy used in this country.

■ *Water Requirement.* The amount of water which must be added to soil by irrigation or rainfall to support plant growth depends on the water-holding capacity of the soil, the local climate (temperature, humidity, and distribution of annual precipitation), and the needs of the particular plant. Five acre-feet of water (water five feet deep per acre) per acre per year is a typical water need for crops grown intensively in the southwestern U.S., an area suggested as ideal for an energy plantation because of its intense sunshine and vast areas of public land available through government subsidies. (Actually, seven acre-feet per acre per year must be added, because some water runs off or percolates downward and is lost to plant use.) Multiplying the sugar cane plantation acreage in Table 2 by five feet, we obtain 740,000,000 acre-feet of water needed to irrigate the biomass to be used to provide the annual U.S. energy requirement. By comparison, the mean annual discharge of the Colorado River, the largest river in the region, is only 13,500,000 acre-feet under natural conditions – or less than 2 percent of the projected annual requirement.

■ *Nutrient Requirements.* In addition to sunlight and water, plants require relatively small amounts of nitrogen, phosphorous, and potassium, as well as other elements and organic substances in trace quantities. On a national scale, however, these mineral requirements are huge.

It is known that a 50-ton cane crop annually removes from the soil 75 to 90 pounds of ammonia (NH_3), 50 to 60 pounds of phosphate (P_2O_5), and 150 pounds of potash (K_2O).[5] To produce 18.18 quadrillion Kcal at 4 Kcal per gram of cane requires 5 billion tons of cane. Five billion tons of cane would require at least fifteen billion pounds (or 7.5 million tons) of potash fertilizer, to take just one nutrient example, every year. Table 3 lists annual nutrient requirements for potash, ammonia, and phosphate. The annual number of 60-ton hopper cars which would be needed to deliver all these fertilizers is 666,000 cars – or about eighteen trains per day discharging their contents into our hypothetical super-plantation.

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1000-Megawatt Equivalents

Clearly, it would be impractical to try to satisfy *all* our energy requirements through the use of biomass. Short of that, however, there is great interest in the more limited goal of generating sizable amounts of electricity by burning bio-fuels. For this reason, it is instructive to calculate the resource requirements for fueling a 1,000-megawatt (MW) electric power station, a huge facility but, nevertheless, the size that is now favored by some utilities. A 1,000-MW plant working at a load capacity of 80 percent and an efficiency of 33 percent requires about 72 trillion Btu of fuel every year. This is almost exactly 0.1 percent of the total U.S. energy used each year. Therefore, the resource requirements of a biomass-burning 1,000-MW plant can be determined by multiplying all the figures in the preceding tables by 0.001. For example, 4,560 square miles, an area almost the size of Connecticut, would be required to pro-

TABLE 2
[illegible] PLANTATIONS

[illegible]	[illegible]	Millions of Acres Required	Millions of Square Miles Required	Percentage of U.S. Land Area
[illegible]	[illegible]	2,916	4.56	124
Old field	[illegible]	914	1.43	39
Cornfield	6,600	692	1.08	29
Scotch pine plantation	7,670	593	0.93	25
Sugar cane plantation	90,000	148	0.23	6

Total U.S. [illegible] 1972: 72.16 quadrillion Btu, or 18.18 quadrillion Kcal.
Total U.S. [illegible] square miles.
Source: References [illegible]

TABLE 1
ENERGY PLANTATION PRODUCTION

Plant Community	[illegible]	[illegible]	[illegible]
Cool temperate forest	1,540	[illegible]	[illegible]
Old field	4,900	79	[illegible]
Cornfield	6,600	104	[illegible]
Scotch pine plantation	7,670	123	[illegible]
Tropical forest	18,000	[illegible]	[illegible]
Sugar cane plantation	90,000	450	[illegible]

Note: Rounding errors cause some numbers to slightly [illegible] when calculated by different paths.
Source: References [illegible]

TABLE 2

FERTILIZER REQUIREMENTS FOR CANE TO MEET U.S. ENERGY NEEDS

Fertilizer	Millions of Tons	Number of Rail Cars Required to Ship
Potash	7.5	125,000
Ammonia	5.0	83,000
Phosphate	27.5	458,000

Source: Reference 5.

vide the cool temperate forest biomass fuel. At the other end of the scale, about 230 square miles would be needed for intensively grown and harvested sugar cane. Water requirements, assuming 5 acre-feet per acre per year for a cane-powered electric plant, would be 740,000 acre-feet, or about 74 times the amount of water used for cooling during operation of the generating plant itself. Annual nutrient requirements, using sugar cane, would be: 5,000 tons of ammonia, 27,500 tons of phosphate, and 7,500 tons of potash.

It can be argued that the resource requirements for a biomass-fueled 1,000-MW plant are just as unreasonable as are those for supplying all our power; they would require only one-thousandth of the resources but would release only one-thousandth of the power. To produce 1,000 MW of electricity by bioconversion for Vermont, for example, it would be necessary to harvest the annual productivity of roughly 4,500 square miles of its forests — almost half its total area, an obviously impossible task.

Six percent of the U.S. land surface would be required for sugar-cane plantations if cane were used to provide all of the energy needs for the country.


USDA SCS Photo

Impact on the Soil

An energy plantation, as usually conceived, is simply an extension of intensive agriculture with its reliance on pesticides, combines, irrigation, and airplanes. The Stanford Research Institute Report notes: "The objective of such a plantation would be to produce the greatest amount of biomass possible per unit of time and space, at the lowest possible cost, and with a minimum of energy expenditure." The concept of the biomass plantation embodied in these words is but a distillation of the general goals of a technocratic society as described by Lewis Mumford:[6]

"From these general postulates a series of subsidiary ones are derived: There is only one efficient speed, *faster*; only one attractive destination, *farther away*; only one desirable size, *bigger*; only one rational quantitative goal, *more*. On these assumptions the object of human life, and therefore of the entire productive mechanism, is to remove limits, to hasten the pace of change, to smooth out seasonal rhythms, and reduce regional contrasts — in fine, to promote mechanical novelty and destroy organic continuity."

Because the goals of the energy plantation, like those of modern U.S. society itself, are to produce more and to do so as fast and as cheaply as possible, it is not surprising that environmental impacts have been given relatively little attention. Emphasizing the cleanness of solar power and guided by technocratic ideals, those responsible for biomass plantations could cause gradual ecological damage of great magnitude. One form this damage would take, unless great care were taken to prevent it, would be the progressive deterioration of soil quality under intensive cultivation. In ordinary agriculture the inedible parts of the crop are often returned to the soil in order to maintain a supply of organic matter which decays into humus. But in certain bioconversion techniques the entire crop, sometimes even the roots, would be harvested and ultimately oxidized by combustion. Organic matter returned to the soil (humus) has many functions: It is a source of nutrients for plants; it improves soil structure, drainage, and aeration; it increases the soil's water-holding and ion-exchange capacities; it enhances mineral weathering, thus releasing nutrients; and it serves as an energy source for the entire community of soil-dwelling organisms.[7] All of these functions will falter if the consumption of humus outstrips its production. That this would occur is guaranteed by the necessity of harvesting as much biomass as possible on the energy plantation.

One of the major functions of humus is that of supplying nitrogen to growing plants; in a natural state more than 80 percent of soil nitrogen is in humus. Experience has shown that continuous applications of inorganic nitrogen fertilizers cannot substitute for the natural reserve of organic nitrogen in humus. If soil humus gradually disappears, as it will under a policy of no organic return to the soil, soil structure will be impaired and oxygen diffusion through the soil will be retarded. As a result of this oxygen depletion, plant roots will become less efficient at absorbing soil nitrogen. Hence, increasing doses of inorganic nitrogen fertilizer will be employed to maintain productivity. With less nitrate fertilizer being absorbed, more will run off the land, causing water pollution and potential human health problems.[8]

During combustion to generate power, not only would organic matter be lost, but the nitrogen in the woody tissues would go up in smoke, and the furnace ash would retain much of the phosphorous and potassium. If returned to the soil, this ash would be of some nutritive value; nevertheless, in sugar cane ash "the proportions [of valuable nutrients] are not large, and the plant foods, owing to the partial fusion of the ash, are not readily available to the crop."[9]

The loss of nutrients and organic matter by combustion emphasizes the infinite superiority of *digesting* biomass rather than burning it. Digestion produces liquid or gaseous fuels and leaves a solid sludge containing most of the original nutrients. The sludge, though awkward to handle, is a rich fertilizer.

Breaking the Food Chain

One of the most basic natural principles is the transfer of energy along a food chain. Some fraction of the sun's energy captured by a forest is harvested by, say, herbivorous insects which in turn may be consumed by birds. Larger animals may then prey on the birds. Harvesting trees for lumber or fuel removes the resource base of all the animals and plants in the forest community. By replacing a prairie with cornfields or sugar cane plantations, the diverse biota dependent on prairie plants vanish. In short, by channeling a large fraction of the primary production of the earth to fulfill human needs, human beings destroy the diversity of the earth.

As E. P. Odum has pointed out,[10] the tendency in natural ecosystem development is toward less production per unit of biomass, greater stability of communities, and, in general, a more finely tuned organization. The tendency in agriculture, intensive forestry, or bioconversion is in the opposite direction – toward maximum production through monocultures, with their well-known susceptibility to disease, a manifestation of instability.

Summary

In the foregoing analysis, we have calculated the minimal resource requirements for growth of different plant communities in two situations. In the first situation, the resulting biomass would supply all U.S. energy requirements; in the second, the biomass would be used to fuel a single 1,000-MW electric plant. Our analysis shows that to supply resources for the first situation would be impossible: All the natural plant productivity of the entire country, that is, from all the plants covering the entire land surface, would somehow have to be harvested each year; or, as an alternative, at least 6 percent of the U.S. land surface would have to be turned into intensive energy plantations, all featuring one type of plant. In addition, it would be infeasible to deliver millions of acre-feet of irrigation water per year to the plantations. Similarly, supplying the required 666,000 rail cars of various fertilizers each year seems a far-fetched concept.

As to natural processes, it may seem unimaginable that the equivalent of half a million boxcars of nutrients is normally processed by plants each year or that Mississippi-sized rivers of water pour into vegetation, but such is the case. The process goes unnoticed because it is diffuse. Plants are everywhere, capturing sunlight, pumping water and cycling nutrients. Natural growth may be slow, but it occurs everywhere and is a mighty natural force in the world.

If bioconversion is approached with an awareness of the natural resources required by plants and the soil, water, and community resources dependent upon them, its practice need not be malignant. It is only through sound husbandry practiced by those who reject the technocratic ideal of more, faster, and cheaper that bioconversion can become a useful, benign source of energy.

Nevertheless, given bioconversion's inevitably small contribution to energy production, would it not be wiser to do without the small amounts of energy so produced and save the land from energy farming? For instance, if all automobiles in the country were fitted with manual transmission and radial tires, we would save over 2 percent of our current total energy use – a figure bioconversion would be hard pressed to match.[11] The same amount of energy could be produced by digesting farm wastes prior to returning them to the land.[12]

Natural resources, in their natural state, support a diverse and stable community with all its attendant functions. Before we divert more of these resources to serve our own needs, we should be aware that the life-support-ing systems provided by these resources can be destroyed. ☐

The title of this article as originally submitted was "An Environmental Critique of Solar Power by Bioconversion." The publisher and editors of Environment are responsible for the published titles and subtitles, selection of photographs and lead-in excerpts, photo captions, and preparation of most graphs and illustrations which appear in Environment articles.

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In the face of increasing costs of gas and oil, wood burning is becoming a welcome supplement or even an alternative to conventional heating methods.

Gibralter

Photosynthetic Solar Energy: Rediscovering Biomass Fuels

Firewood is still a familiar fuel in much of the United States, but somehow it does not come up in discussions of national energy policy very often. Yet wood was the primary U.S. fuel only a century ago and is still the main source of energy in most of the developing world. As recently as World War II, Sweden, cut off from oil imports, derived virtually all its fuel from wood. Since the Arab oil embargo there has been renewed attention in many countries to the energy potential of diverse forms of biomass—wood, sugarcane, algae, and even material produced by artificial photosynthetic processes.

Wood and dry crop wastes have an energy content of 14 to 18 million Btu per ton, comparable to that of Western coals. Raw biomass contains virtually no sulfur and little ash, however, and except for some difficulties in handling it is as easily burned or gasified as coal. Other chemical and biological conversion techniques exist too, most notably fermentation of sugar and grain crops to ethyl alcohol, and anaerobic digestion of wet biomass wastes to methane. Thus biomass is potentially a renewable source of a full range of storable liquid and gaseous fuels for which domestic sources of their fossil counterparts are increasingly in short supply.

This is the fifth in a series of Research News articles examining recent developments in solar energy research.

Biomass is already the largest source of solar energy in use in the United States. In recent years nearly half a million modern woodburning stoves have been sold—an installed energy capacity that far outstrips all other direct and indirect solar energy devices. The wood products industry now derives an even larger amount, 40 percent of its total energy needs, or about 1 quad (10^{15} Btu) from burning bark and mill wastes. Several recent studies done for the Energy Research and Development Administration (ERDA) suggest that annual production of biomass fuels could conceivably reach 10 quads by the year 2000.

Except for analytical studies, however, the federal energy research program has largely downplayed the biomass option. The ERDA biomass effort initially focused on municipal wastes, a choice that is now generally conceded to have distracted attention from more significant possibilities. The remaining effort has concentrated on the long-range prospects for conversion of biomass to liquid and gaseous fuels and has been meagerly funded—currently $9.7 million compared to more than $300 million for coal-based synthetic fuels. Direct combustion of biomass and other near-term applications appear to have been neglected.

State and private efforts have been more aggressive. The California Energy Resources Conservation and Development Commission (ERCDC) has revived a gas producer copied directly from old Swedish designs. According to Robert Hodam of ERCDC, the gasifier is capable of converting nearly any kind of dry agricultural or wood wastes to low-Btu gas with an efficiency of 80 to 85 percent. The gas can be burned in a boiler in place of oil or natural gas. Although ERDA rejected a request to co-fund a demonstration of the device on the grounds that it was not sufficiently novel, ERCDC went ahead. A test unit at a Diamond-Sunsweet walnut factory near Stockton, California, has operated so successfully on walnut shells that the company has decided to build a larger (130 million Btu per hour) gasifier to provide all its energy needs. Based on bids already received, the company expects the gas to cost about $1 per million Btu, less than half the cost of the natural gas it now burns.

The demonstration has generated considerable interest in dozens of other companies with substantial biomass wastes and a major farm equipment manufacturer is planning to build and market them for farm applications. Hodam estimates that in California alone, where already collected lumber and mill wastes exceed 5.5 million tons per year, the gasifier has an immediate potential for displacing 0.1 quad of oil and natural gas.

The overriding uncertainty about biomass energy is the extent of the resources that are or could be available. Those that can be used immediately are small compared to the 75 quads of energy now consumed by the United States every year, and biomass cultivation for energy on a large scale may not be economic. Moreover, most agricultural scientists believe that energy uses of biomass must coexist with needs for food and fiber, so that very large areas of prime land may not be available exclusively for energy crops in the United States, although they may be in other countries such as Brazil (*Science*, 11 February, 1977, p. 564). Nonetheless, there is increasing optimism among biomass analysts that substantial amounts of energy could be available even in this country from wastes, and from field, tree, and aquatic crops.

According to a study done for ERDA by the Stanford Research Institute, 277 million tons of U.S. agricultural residues are potentially collectable per year; an additional 26 million tons of manure could be collected from feedlots. Corn stalks, husks, and cobs in particular are regarded as readily available in quantities that could produce as much as 1 quad of energy in corn belt states that now consume large quantitites of propane and liquefied petroleum gases (LPG) to fire crop dryers and other farm equipment.

Sugarcane and sweet sorghum, as well as corn itself, might prove to be good energy crops. A study by Battelle Memorial Institute concluded that there might be a substantial near-term market for industrial alcohol (ethanol) fermented from these materials. About 300 million gallons a year of industrial alcohol are now made from ethylene, which in turn is made from natural gas or petroleum. Battelle's estimates are that biomass ethanol from a full-scale plant could sell for $1 to $1.25 per gallon, compared to about $1.15 per gallon for ethanol from ethylene. According to Edward Lipinski of Battelle, the study director, further cost reductions in biomass ethanol are possible if the processing equipment could be operated year-round and not just during the sugarcane harvest; for example, a mill could stockpile molasses, a sugar by-product, and ferment it when the cane harvest was over, or use sweet sorghum, a high-yield tropical grass that can be grown as a second crop in sugarcane areas. There is also growing interest in the idea that a second, energy-related market could help stabilize U.S. sugar and grain prices in years of plenty—a concept that has worked well in Brazil.

Some investigators have proposed that biomass ethanol can already be made cheaply enough to compete with gasoline as a motor fuel in some parts of the United States. Large commercial facilities to produce ethanol for blending with gasoline are under consideration in Nebraska, where there is an excess of spoiled or poor-quality corn, and in Hawaii, where fuel prices are high and sugarcane is abundant.

Forest wastes in the United States are nearly as large as those from agriculture. They total about 24 million tons per year in unused mill wastes and 83 million tons left on the ground in the forests with current harvesting methods, according to a recent report by the Mitre Corporation. This report concludes that as much as 4.5 quads of energy per year could be produced on just 10 percent of now-idle forest and pasture land with wood grown in close-spaced, short-rotation tree farms using poplars, eucalyptus, or other high-yield species.

The forest products industry does not yet think of itself as a potential energy producer and some industry spokesmen are skeptical that biomass in the quantity proposed in the Mitre report can be produced without cutting into the timber and paper markets. But a feasibility study done by the Forest Products Laboratory in Madison, Wisconsin, points out that the Swedish forest industry is already producing 60 percent of its own energy needs and concludes that the U.S. forest industry could come close to being self-sufficient in energy by 1990 using wastes alone—a development that would expand present production from 1 to almost 3 quads of biomass energy.

Experiments by Claud Brown at the University of Georgia forestry school show that sycamore planted in rows and harvested at 5 years of age yield 10 to 16 tons of biomass per acre per year, three times the yield of traditional long-rotation silviculture. The younger trees prove easier to harvest with mechanical equipment and are of suitable quality for either energy or pulp production. Brown also points out that the breeding and genetic manipulation techniques which led to modern high-yield grains are only just beginning to be applied to forestry, so that substantial improvements, perhaps more than a doubling in yield, can be expected. Other investigators point to a huge unused reserve of wood—exceeding 10 quads—that is contained in stagnant stands of noncommercial species or diseased trees; if harvested, this biomass could have a major near-term local impact on energy supplies in New England or the Great Lakes region.

A third major category of potential biomass resources is aquatic plants. William Oswald of the University of California at Berkeley has proposed growing blue-green algae on sewage wastes and has obtained yields of 16 to 32 tons of dry biomass per acre per year. Algae are readily converted to methane by anaerobic digestion, but they also are rich in protein and may lend themselves to the joint production of energy and food. Water hyacinth, a rapidly growing plant that now clogs many inland waterways, has also been proposed as a potential feedstock for methane production.

An even more ambitious proposal, by Howard Wilcox of the Naval Undersea Center in La Jolla, California, is to grow huge rafts of kelp in the open ocean as sources of methane, animal feeds, and chemicals. To feed the kelp, nutrient-rich water would be pumped up from the lower levels of the ocean. The proposal has attracted the interest of the gas pipeline industry, which is helping fund preliminary research. The project may face environmental objections, however, because deep-ocean water is also rich in carbon dioxide, so that the artificial upwelling would by one estimate release three times as much carbon dioxide to the atmosphere per unit of energy gained as would the burning of a comparable amount of coal or oil.

An alternative approach to biomass energy is to try to improve on the efficiency of plants as photosynthetic solar energy collectors. The highest sustained yields reported for any plant approach 50 tons per acre per year for sugarcane—which Melvin Calvin of the University of California at Berkeley describes as "the best, most efficient solar energy device we have today on a large scale." Quanta of visible light converted photosynthetically to chemical bonds represent 50 to 90 kilocalories per mole of captured energy, whereas the same quanta captured as heat at 700°C represents only about [illegible] kcal/mole. But only about 4 percent of the light reaching the cane is used in photosynthesis. To overcome this limitation, Calvin is working on the construction of an artificial membrane system that could produce hydrogen from water by simulating the photosynthetic process. He believes that efficiencies as high as [illegible] percent should be ultimately attainable and that artificial photosynthetic methods may be achieveable within 15 years.

Despite innovative ideas and claims of feasibility for a wide range of proposals, the economics of most biomass energy systems are still uncertain. Relatively few experimental efforts or field trials have been conducted, especially with crops grown for energy production, and most cost estimates are based on analytical studies or are extrapolated from outmoded equipment. These preliminary estimates are encouraging, however, and the competitiveness of biomass fuels seems certain to increase as supplies of oil and gas dwindle and costs rise. Synthetic fuels from coal now appear likely to cost between $4 and $5 per million Btu, a target that many investigators believe can also be met with biomass systems capable of large energy yields.

One aspect of the ERDA program for synthetic fuels from biomass that concerns many biomass specialists is, paradoxically, its focus solely on energy. They point out that in the United States biomass production is so embedded in the food and fiber industries as to make multiple use of biomass resources the most economical approach. Lipinski, for example, points to the potential of using corn as a feedstock for alcohol production, corn husks and stalks as fiber for paper production or fuel for grain drying, and the protein-rich stillage left over from alcohol fermentation as an animal feed—all of which are already being pursued separately. There is as yet no experience with and no funding for integrated processing facilities—biomass refineries—and some critics doubt that ERDA or its successor, the new Department of Energy (DOE), is institutionally capable of such an integrated approach. They note that DOE does not have a network of field stations capable of testing and tailoring multiple-use biomass processes to meet the various needs of farmers and foresters in different regions and that the Department of Agriculture, which does have such a network, has no charter in the energy field.

One novel idea for a biomass refinery is that proposed by Michael J. Antal, Jr., of Princeton University. He suggests producing hydrogen from organic wastes with steam generated by solar heat concentrated on a boiler. According to his calculations, such a refinery might process crop residues gathered from a "watershed" of 70 square miles, about [illegible] tons per day; the hydrogen that results would have an energy content 36 percent greater than that of the raw biomass and cost less than hydrogen made from natural gas. The efficiency of the combined solar-thermal and biomass process is estimated to be higher than 70 percent, in part because steam reforming makes use of the moisture contained in most biomass rather than using a portion of the energy to drive it off first.

Biomass is such an obvious and ubiquitous resource that its energy potential has been largely overlooked. New ideas for how to tap this potential are appearing at a rapid rate and many of them may be applicable in the near term. Before the United States is faced with the necessity of committing hundreds of billions of dollars to a fossil-based synthetic fuel industry, it would be advantageous to explore much more thoroughly whether biomass fuels can also play a major role.

—ALLEN L. HAMMOND

Five solar water heaters you can build

By EDWARD MORAN

Five PS readers, in widely scattered sections of the country, share their DIY expertise in this article. Tax incentives and enlightened building codes are finally beginning to catch up with the know-how. If you don't have a "solar thumb," check out the off-the-shelf systems on page 104. For more DIY tips, see page 142.

Ken Herrington, the evolution of a system

Ken Herrington just can't say no when it comes to homegrown energy. When we featured his fireplace heater in this series [PS, July '75], we weren't aware that we'd met up with an avid craftsman who is turning his ranch on a northern California hilltop into a veritable alternate-energy lab.

Over the months, we've been fed dozens of photos (Herrington is a

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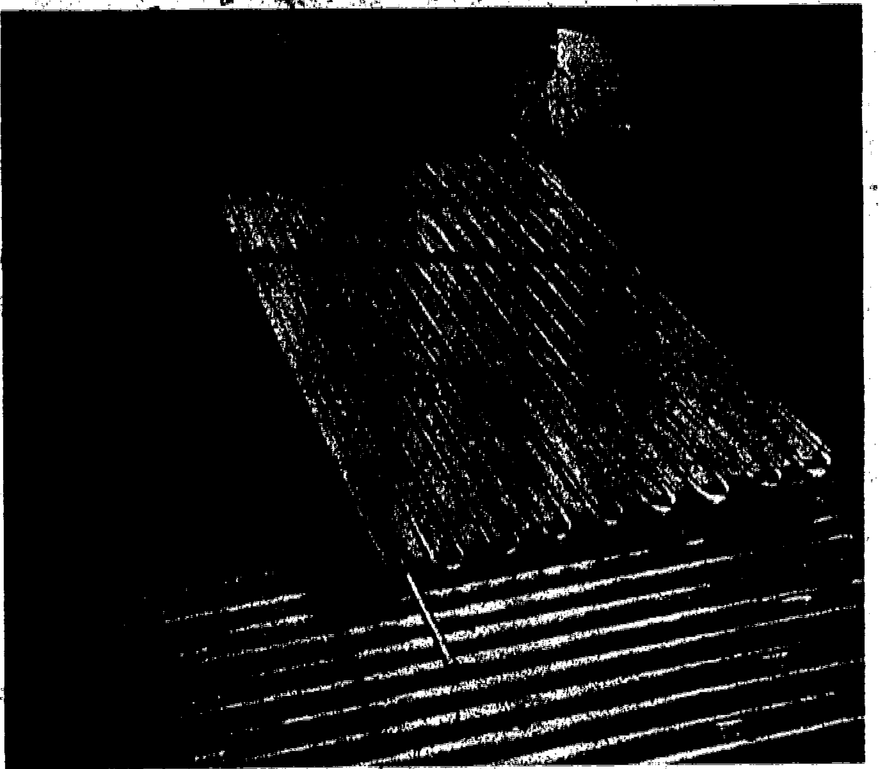
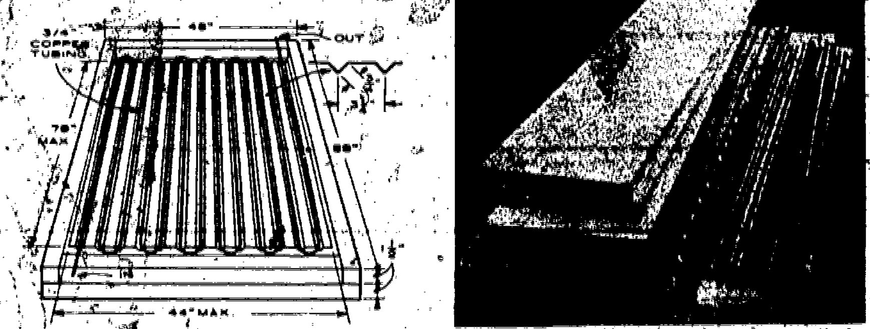
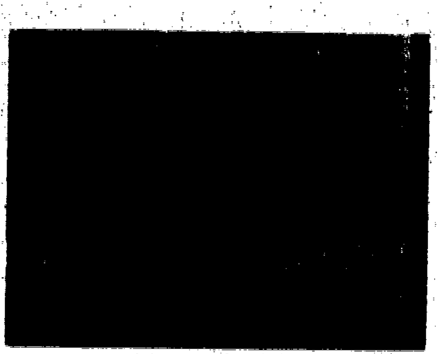


Here's a dimensioned drawing



1 Number and spacing of V grooves can be varied (compare drawing and photo). Shown: 4-by-8-by-1½" beadboard panels, 17 tubes of 80-by-¾" copper; 16 sets of copper return bends and couplings, and plywood (optional). Also needed: a 78-by-43-in. sheet of 24-gauge galvanized metal, and fiberglass.

2 To form a tray for the piping, glue beadboard strips to flat beadboard panel, driving in ¼" wood dowel to hold surfaces together firmly.



3 After edges are set, glue an inch of fiberglass insulation into place with butyl-rubber cement from adhesive caulking tube. Pipe grid goes on top.

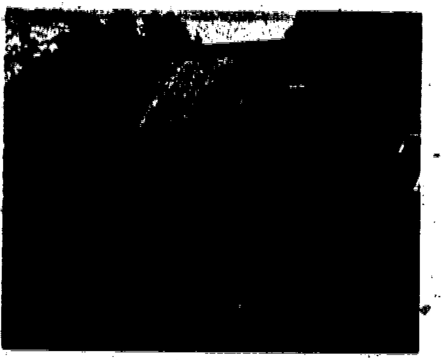
4 Pipes are soldered into V grooves in sheet-metal plate. If the copper return bends are unavailable, use street ells and couplings, as here.

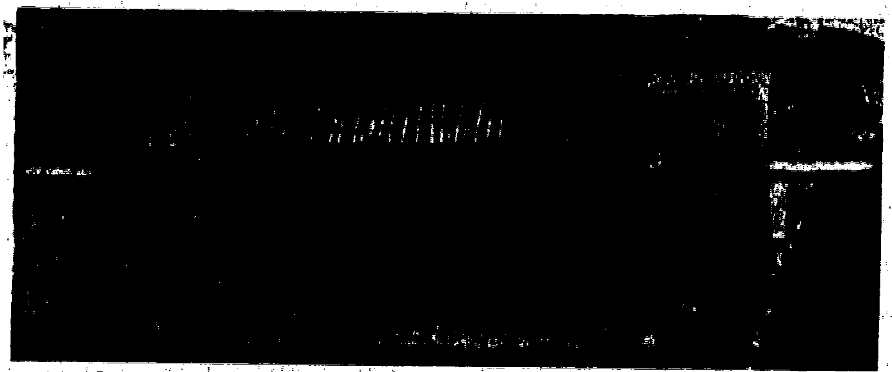
5 Earlier version used strips of V-grooved metal held together with sheet metal screws. You may find this easier to keep flat while soldering.

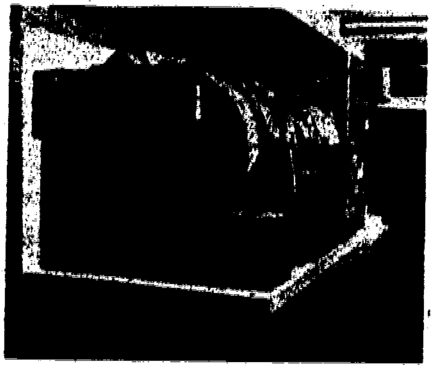
6 Use a C clamp to hold strips in place while screwing them together. Continuous beads of solder are run down both sides of each pipe.

7 Seat the piping assembly in the beadboard box. Paint flat black, then attach glazing in plywood frame; bolts along edges hold it together.

Condensation can fog single-glazed unit, reducing insolation. Herrington recommends spraying cover with moisture retardant, such as Sun Clear. In photos at right, paper mask shows effectiveness; treated area stays clear on dewy morning, next day. **Heat-exchanger tank** (bottom) holds 80 gallons. Copper tubing brings solar-heated water to heat tap water inside. Mallett-bend tubing around tank, cover with Thermon cement, foil, 4" foil-backed fiberglass, then brick up in basement (right) to retain heat. (Photo shows incomplete installation; bricks are later boxed in.)







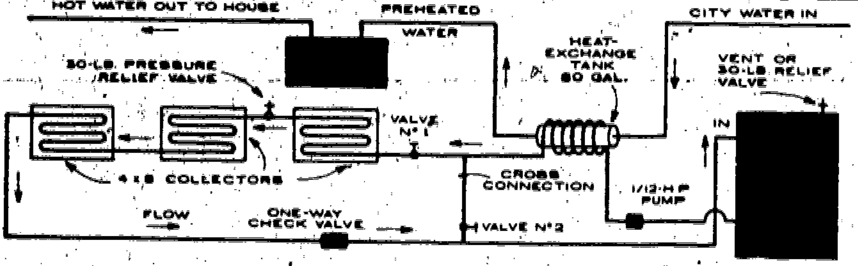


Diagram shows possible setup, linking three 4-by-8 solar panels into a conventional hot-water system for backup. Check valves permit solar collectors to be bypassed at night or on cloudy days, when you'd draw on stored water. Pressure-relief valve is necessary to prevent damage in case of steam buildup. For most American climates, heat-exchange system is recommended.

topnotch industrial photographer) of solar pool heaters, solar greenhouses, solar water heaters, storage tanks, piping, heat exchangers —each device carefully built and tested by this do-it-yourselfer.

We asked Herrington to show us plans for an inexpensive, easy-to-build collector that a typical homeowner could put together with a few tools and a little spare time. Materials for the collector shown in photo 1, cost exactly $160.73, wholesale; assembly takes a few hours.

This model is by no means Herrington's first version; and we're sure it won't be his last; he sees solar research as an evolving process, and is always making innovations. His first 4-by-8 collector, built last year, was little more than a plywood box with a flat metal plate to which copper tubing had been soldered. Later, he added fillets of heat-transfer cement to improve performance. Then he came up with the idea that's the basis for the collector described here: Instead of merely soldering pipes to a flat plate, he reasoned, why not first nestle them in V-shaped grooves?

At first, he used individual strips of metal, crimped V's down the center, then screwed them together (photos 5 and 6). A much simpler method is shown in photo 4: You can ask a sheet-metal shop to punch out a 24-gauge sheet to the specs given in our drawing.

The original plywood box has given way to one made from steam-expanded polystyrene (beadboard), which costs about $10 for a 4-by-8-by-1½" panel. (Herrington also recommends Celotex's Technifoam, slightly more expensive, but more durable.) Edging for the box is a 1½"-wide strip (cut from another beadboard panel) glued around the perimeter (see photo 2). An inch of fiberglass insulation (photo 3), avoids any danger of the beadboard melting due to the heat of the pipes.

The 4-by-8 size was chosen to take advantage of standard materials sizes. Copper pipe comes in 20' lengths, which can easily be cut to three 80" lengths. With return bends or street ells added (photos 4 and 5), the piping assembly should just snug into the beadboard box (photo 7). Before inserting, though, clean all surfaces thoroughly with soap and water, then cover with a flat black paint.

Herrington doesn't think double-glazing is necessary in his climate; it would prevent convective heat loss more effectively in colder areas. He single-glazes with Kal-lite premium fiberglass cover (.025" thick), bolting it in a frame of plywood strips and sealing it with butyl-rubber silicone.

From collector to system

The diagram is Herrington's proposal of how a three-panel system might be hooked up to provide hot water for a typical household. Panels can easily be placed on a south-facing roof; or, if you have the space—as Herrington does—mount them on the ground or on a fence.

"Summer heating of hot water in my climate is simple," he tells us; "a 32-sq.-ft. collector should supply all my needs. Winter is a different matter; I need at least 90 to 100 sq. ft. of collector."

Herrington uses the heat-exchanger loop to insure a more constant supply of water on cloudy days and at night. Also, since he uses a water conditioner to prevent rust and foam (Rust Raider Heating System Conditioner), he must keep his tap water separate from the water that is pumped through the system.

Performance

In winter, the preheated water may leave the heat exchanger at 95°; on a sunny summer day, it might be as high as 130°. Space doesn't permit us to detail all the careful monitoring Ken Herrington has made on his system. He would rather err on the side of caution, so intent is he on not making any unwarranted claims.

Some figures he sent us for the middle of February are instructive. During a week in which daytime temperatures ranged from 50° to 61°, he reports tank temperatures rose by 40° to 50° each day, when the solar system was working (from 80° to 121° the first day; from 100° to 150° the next). This works out to a mean of about 180 Btu per hour per square foot of collector.

Further performance data are included in a data packet Herrington is offering for those who want more information. Send $5 to Ken Herrington, 769 22nd St., Oakland, Calif. 94612. If you want to ask a specific question (free), include a stamped, return envelope.

J. Don Field, rooftop 'trickle' collector

Not to be outdone by Ken Herginton's elaborate system, a Roanoke, Va., experimenter, working independently from previous PS articles, has also been checking out solar water heating.

Photo and diagrams illustrate the 42-sq.-ft. aluminum collectors that Field installed on his due-south-facing roof more than a year ago. It's a trickle collector: Water flows directly over a corrugated-aluminum surface backed by a slab of insulation—turn page for assembly sketch. (At press time, Field reports some success with a new copper-tube collector he built recently.)

Materials for the aluminum unit cost Field about $300. He reports average monthly savings of $7 (150 to 165 kw shaved off his power bills), so payback time is about four years.

As with Herrington's system, this setup needs a heat exchanger: If an aluminum collector is used, it's a good idea to mix in water inhibitors to prevent corrosion. Field retains his electric water heater as a backup.

Collector assembly

Field chose aluminum over copper for its lower price, and a 3'-by-16' collector size for the convenience of using standard-cut lumber. A basic box is first made by nailing 2-by-4's to a sheet of 4-by-8-by-½" plywood. Next, add a 1½"-thick layer of insulation. Initially, Field used Styrofoam, but

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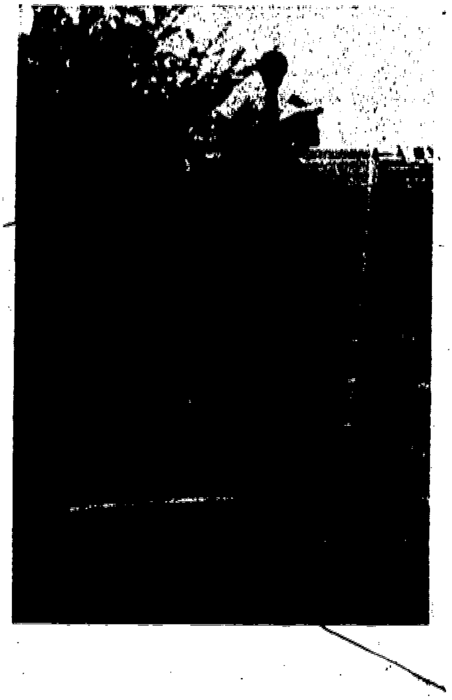


now recommends using fiberglass.

Atop the insulation goes one sheet of temper-rib aluminum roofing painted flat black. A collector pan at the lower end leads to a ¾" PVC drain line. The entire collector is covered with double-strength window glass.

A year ago April, Field was ready to test the collector, using a temporary five-gallon tank. On a day when ambient temperature was 42°F, he was able to heat the five gallons from 55° to 120° in 90 minutes.

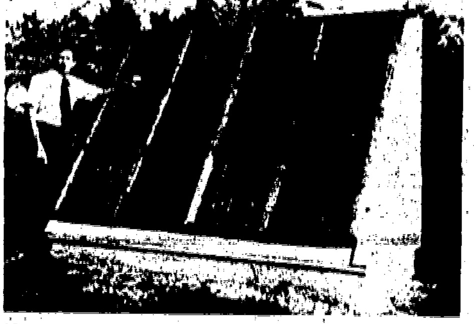
Problems beclouded him, though. Condensation blotted out sunlight, and the aluminum surface became discolored by water passing over it. Field solved both problems by pop-riveting another sheet of black aluminum over the existing one and running water between them.

What good is that sun-warmed water if you don't have it at night, or on a rainy day? Insulated storage is the answer. Field made a 100-gallon tank from two sheets of 4-by-8-by-½" plywood, coated the inside with fiberglass, then wrapped top, bottom, and four sides with two inches of Styrofoam. Later, he decided to add six-mil polyethylene up to the water line inside to prevent leaks. For a heat exchanger, tap water is run through coils of ¾" copper pipe submerged in the tank; this preheated water then ente[illegible] electric heater, nearby.

Pe[illegible]nce varies with season, of cou[illegible]n September and October, [illegible]ecorded average tank tempe[illegible] of 127° on all-sunny days, [illegible]° in early December. In Jan[illegible]d February, with the new cop[illegible]ollector added (which doubled [illegible] original size), late-afternoon tank temperatures generally ranged from 90° to 130°, with a peak of 142° on Feb. 27 (ambient temperature, 70°). Field's electric heater was not used at all from Feb. 10-29.

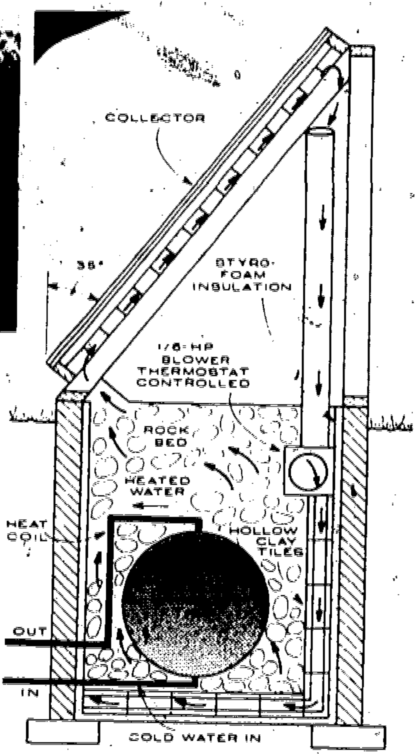
For a specific question, send a stamped, return envelope to J. Don Field, 4601-A Renfro Blvd., NW, Roanoke, Va. 24017.

John Snell, circulating-air collector



If your roof isn't oriented to take full advantage of the sun, don't despair. This Nebraska DIY'er built a freestanding unit in his backyard and linked it to his home plumbing with underground piping.

This project is unique in several ways: Air, not water, is used as the heat-transfer medium; the 48-sq.-ft. collector surface is made of 600 aluminum beer cans stacked in a wood A-frame structure; beneath it, a 180-cu.-ft. underground storage pit acts as a "heat trap" for the heated water.



Economics. Snell figures he saves about 300 kwh per month (more in summer), for an average monthly electric-bill reduction of about $8 to $12. Total material costs, excluding labor, came to $3 per square foot (about $150), so Snell expects to be home free in less than two years.

Construction. The pit is 4' wide, 9' long, and 5' deep. Its walls are of hollow-core clay tiles (4"-by-8"-by-12") lined with Styrofoam insulation. An 80-gallon galvanized steel tank is buried under five cubic yards of fist-size rocks. As water leaves the tank, it passes through a 40' heat-absorption coil before entering the 50-gallon electric hot-water heater in Snell's basement.

Above ground, the collector housing is made of 2-by-4 framing lumber and ½" exterior plywood sheathing. Snell emptied all the aluminum cans, painted them flat black sunside, and white bottomside, then stacked them in rows with air channels in between. The housing is double-glazed with two 24"-by-24" panels of common window glass, with ⅜" air separation for each section. The collector is oriented due south at 35° from vertical, the proper angle for his latitude.

A ⅙-hp, 1725-rpm split-phase fan circulates heated air through the rock pit; it turns a direct-drive six-inch squirrel-cage blower with suction and exhaust ducts.

Performance. Snell is quite satisfied with output. "High temperatures continue to be in the 125°-135° range, depending on quality and quantity of sunshine," he reports. But after one 10-day sunless period in December, the storage temperature dropped to 55°, the same as the input water.

For specific questions, send a stamped return envelope to John R. Snell, Route 1, Gretna, Neb. 68028.

Ron Hannivig, rooftop

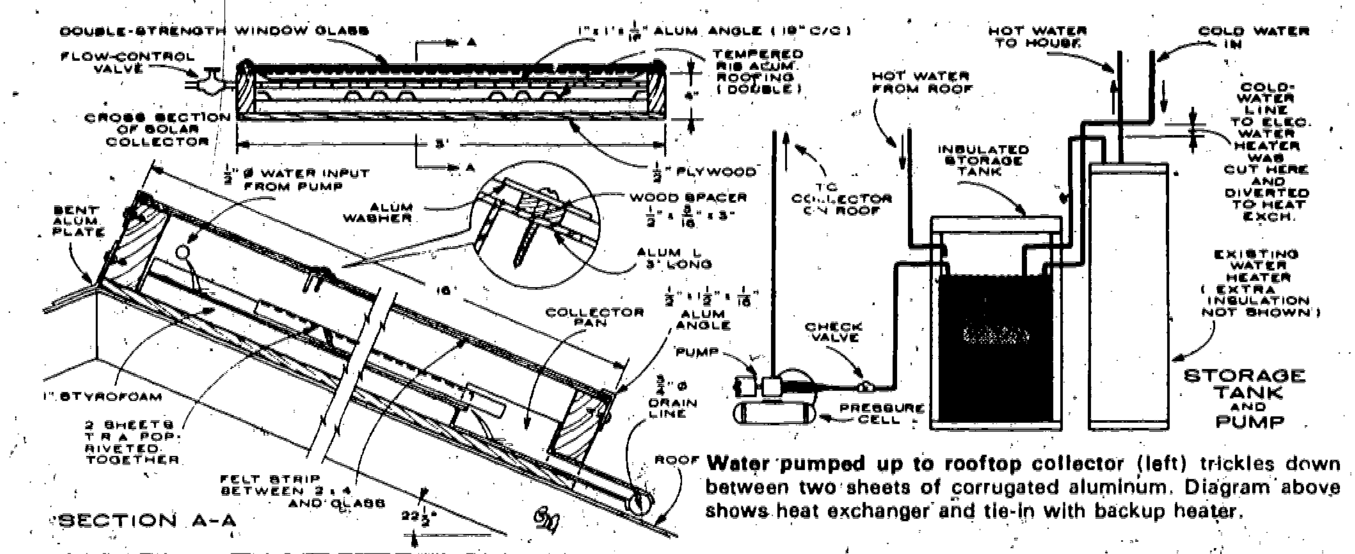
What started as a do-it-yourself project two years ago has since blossomed into a full-time solar distributorship for Ron Hannivig (turn page to next article). The tank/collector module described here is the original homemade version that anybody can try.

Tank and collector are exposed on the roof, so it's a natch for Hannivig's Florida climate. (For colder locations, use the heat-exchanger systems, such as Herrington's or Field's.)

This system works on the thermosiphon principle, thus eliminating the need for a circulating pump: As water in the collector is heated, it expands, rises, and passes into the storage tank. Denser cold water then fills the collector, and the cycle continues as long as the sun keeps shining.

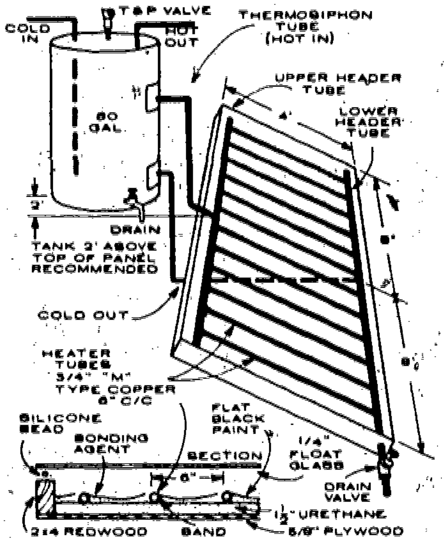
Note that the photo shows *two* 40-gallon tanks: one standing and one lying. Local building codes made this setup more practical, though the drawing shows a single vertical tank, which can be a full 80 gallons, or as big as the system can handle.

Economics. Cost of materials for the collector approximated $250, and the tanks were purchased off-the-shelf for



Water pumped up to rooftop collector (left) trickles down between two sheets of corrugated aluminum. Diagram above shows heat exchanger and tie-in with backup heater.

tank collector



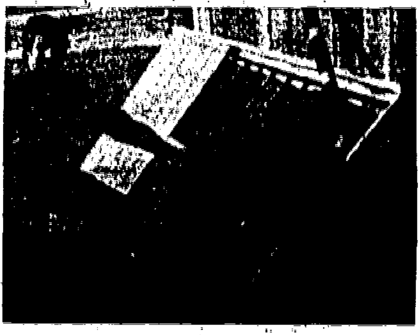
$150. Estimated pay-back time is about three years. Hannivig reports that during the balmy Florida summer, his system can provide up to 95 percent of his family's hot-water requirements; in winter, up to 65 percent.

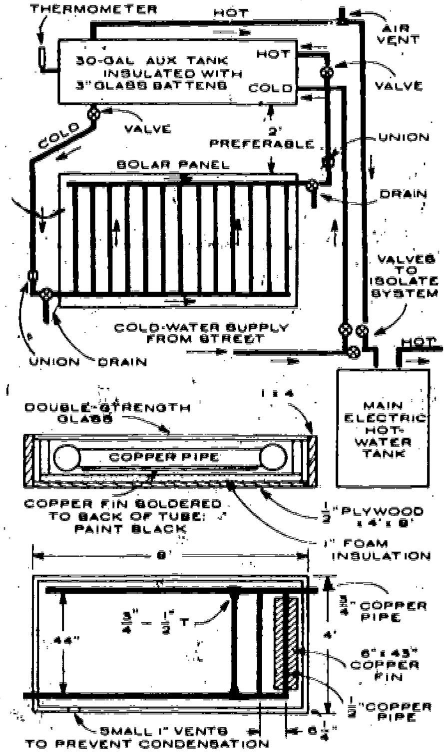
Construction. The wood-frame collector covers 64 sq. ft. (two 4'-by-8' panels) insulated with 1½" of urethane. Three-quarter-inch copper tubing (see diagram) is T-connected and mounted on top of the urethane. In the device shown, sand was packed around the pipes for heat transfer (see detail) and sprayed with a stucco binding agent. Assembly was then painted flat black. Finally, ¼" float glass was silicone-bonded to the sides of the frame for an "effective weather-tight glazing." Pressure-relief valve is a must.

Performance. Hannivig set his conventional electric heater to kick in at 130°, but finds solar-heated water generally available at 135°-140° during the day.

For a specific question, send a stamped return envelope to Ron Hannivig, 2525 Key Largo La., Fort Lauderdale, Fla. 33312.

Peter West, through-the-wall collector





Why allow fuel bills to dampen your vacation? This "summer" heater is the least complicated of the five presented here. Specifically, it's designed to supplement an existing electric hot-water system from March through November at a vacation home on the Delaware coastline, where the mean annual sunshine totals about 2600 hours. Copper was chosen to offset the effects of salt-laden air. The system is not freeze-proof, lacking a heat exchanger.

Once again, the thermosiphon principle is the key (see Ron Hannivig's project, at left). A 4'-by-8' collector panel preheats water that's siphoned to a 30-gallon storage tank ceiling-mounted indoors, several feet above the collector.

Economics. West invested about $200 in materials. His heating figures indicate a gain of 13,000 to 18,000 Btu per day, for a total savings of $40 from May through October. Break-even time: about four to five years.

Construction. For the collector panel, West used two ¾" copper headers and T-soldered them at six-inch intervals to sixteen ½" vertical copper risers. For faster water flow, the risers were designed to run the four-foot width. Pressure-test this piping before proceeding, as West did.

Next, solder 6"-wide copper flashing strips to the back of each riser, using 50-50 lead/tin solder with a good flux. Heat three to six inches at a time, and apply pressure with a wood block as the solder cools. Clean the panel and paint it flat black. Finally, mount the piping in a 4'-by-8' box made of ⅝" exterior plywood to which you have added 1-by-4 sides. Paint the box and line the bottom and sides with one inch of urethane-foam insulation. A 30-gallon galvanized water tank was ceiling mounted, wrapped in four inches of fiberglass insulation, and boxed with ¼" plywood.

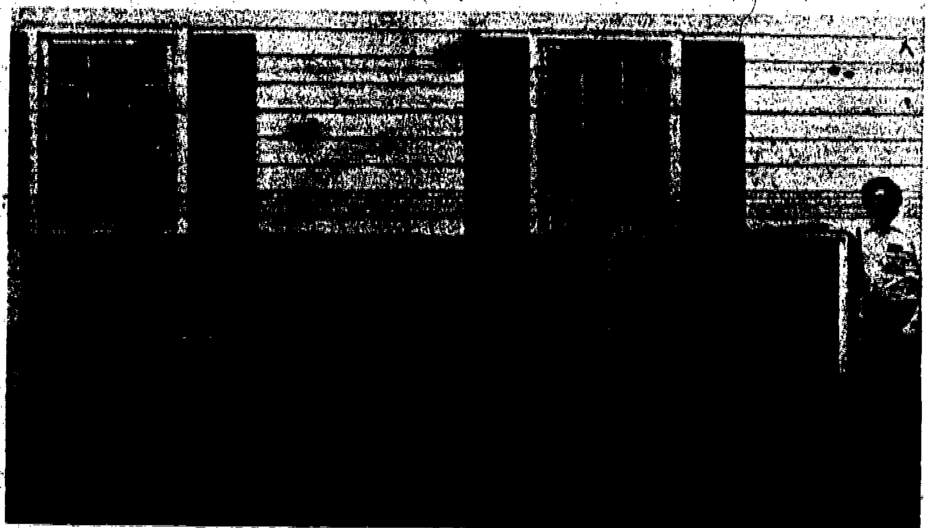
Performance. In a week-long evaluation in mid-July, when water demands were greatest, West reports that the system peaked at 115° in mid-afternoon (original water-in temperature was 70°), and stayed at 95° through 7 p.m. even with demands from washing machine, dishwasher, and showers.

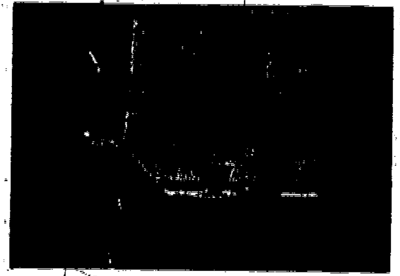
For specific questions, send a stamped return envelope to Peter West, 12901 Melville Lane, Fairfax, Va. 22030.

ADVENTURES IN ALTERNATE ENERGY

A monthly sampling of projects PS readers have devised to conserve or replace fossil fuels

John Des Chenes: Corrugated-plate window collector





Distribution box doubles as plant shelf, doesn't block view. Linda Des Chenes aided project by carefully monitoring temperatures every half hour.

By EDWARD MORAN

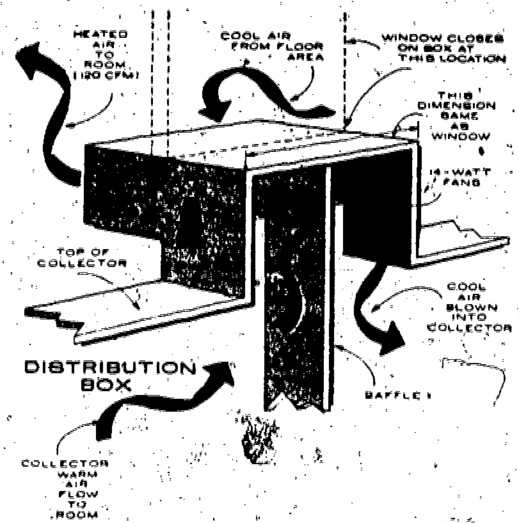
Motivated by a commitment to appropriate technology, New Hampshirite John Des Chenes designed this four-by-16-foot window collector to achieve direct heating (no storage) of his living room. He's built more sophisticated collectors, but feels this type can generate quick payback for the typical handyperson disheartened but not disarmed by rising energy costs.

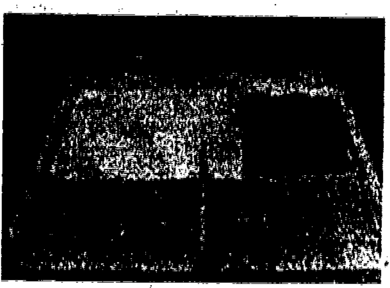
Built for just $75 in materials (that's $1.17 a square foot), the system should pay for itself in 1½ heating seasons, even in northern New England, where 7000+ annual degree days do not come cheaply. **"On sunny days," says Des Chenes,** an engineer with a graduate degree in the field and technical director at a paper firm, "the living room is kept at 70°-78° F from approximately 9 a.m. to 4 p.m. by the collector alone."

Construction details

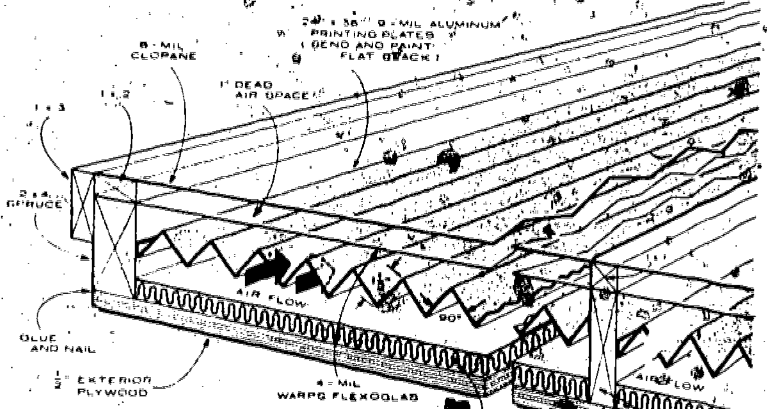
To form the basic box structure, Des Chenes glued and nailed 2x4 spruce strips to the perimeter of two 4x8 sheets of ½" exterior-grade plywood. He then attached a 1x4 rib to the center line (see small

Continued





Warm air enters living room through plenum box that snugs under window, which is weather-stripped at all contact points. Cool air near floor is sucked into plenum by two 14-watt computer-type whisper fans; heated air then enters living room through chamber at left (red arrow). Thermal switch in return plenum actuates fan when temperature of air in collector reaches 80 degrees. Fans shut off automatically in late afternoon or during cloud cover.



SOLAR COLLECTOR DESIGN
(CROSS SECTION)

photo near construction sketch) to act as an airflow baffle and a support for the double glazing. He glued ¾" polystyrene insulation to the sheathing on the inside and topped it with reflective foil for added insulation (to reflect infrared back to the absorber plate).

Des Chenes had access to 24-by-36-in. 9-mil aluminum offset printing plates that had been discarded by a local newspaper; he made his absorber plate by corrugating the plates, bending them over the straightedge of his workbench into V grooves. (Similar corrugated plates can be purchased, of course, if you want to avoid the tedious bending.) He then painted them flat black topside and suspended them over the foil-lined insulation. The V configuration triples surface area—grooves are 1½" deep—and makes for a stiffer surface. Also, the corrugations offset the drawbacks of a vertical-mounted collector: At certain sun angles, energy will not be reflected back out as with a flat-plate collector, but will strike an adjacent surface, "concentrating" the sunlight.

Des Chenes opted for two layers of plastic glazing (lighter and less expensive than glass): 4-mil Warps Flexoglas on the inside and 8-mil Clopane (polished vinyl) on the outside, attached with PVC duct tape and furring strips. "These materials have been entirely satisfactory to date; no clouding, cracking, or excessive stretching has been noticed. A service life of two to three years appears reasonable. Du Pont's Tedlar 5-mil would yield longer service life for a higher initial cost," he reports. See the drawing for details; note the one-inch dead-air space between the glazings.

By making use of solar heat gain as it's produced, without intermediate storage, this collector gains in efficiency over those that produce temperatures that are much higher—but too high for human comfort. Des Chenes is planning, however, to add some form of low-temperature subfloor heat storage to extend heating into the evening hours.

Special effects

Some unexpected paybacks enhanced performance during the first heating season. Relative humidity was one. After several successive sunny days, indoor humidity increased, since moisture from showers, cooking, and laundry was not being sucked into the basement and up the chimney as much as before. Cold drafts into the living room nearly vanished. And the oil furnace did not kick in so often, since the downstairs thermostat was located in the living room. Of course, the kitchen and dining room became cooler, but only to 62-65 degrees. At night, foam-backed insulating drapes are drawn to prevent heat loss. As a result, Des Chenes claims his actual savings in oil to be "much greater than strictly the oil/Btu equivalent of the collector gain." Calculations of degree days and oil consumption indicate a savings of about three times the Btu that the solar panel collects. Last season this translated into a net saving of $58.56. (Electricity to operate the fans costs about $1.20 a year.)

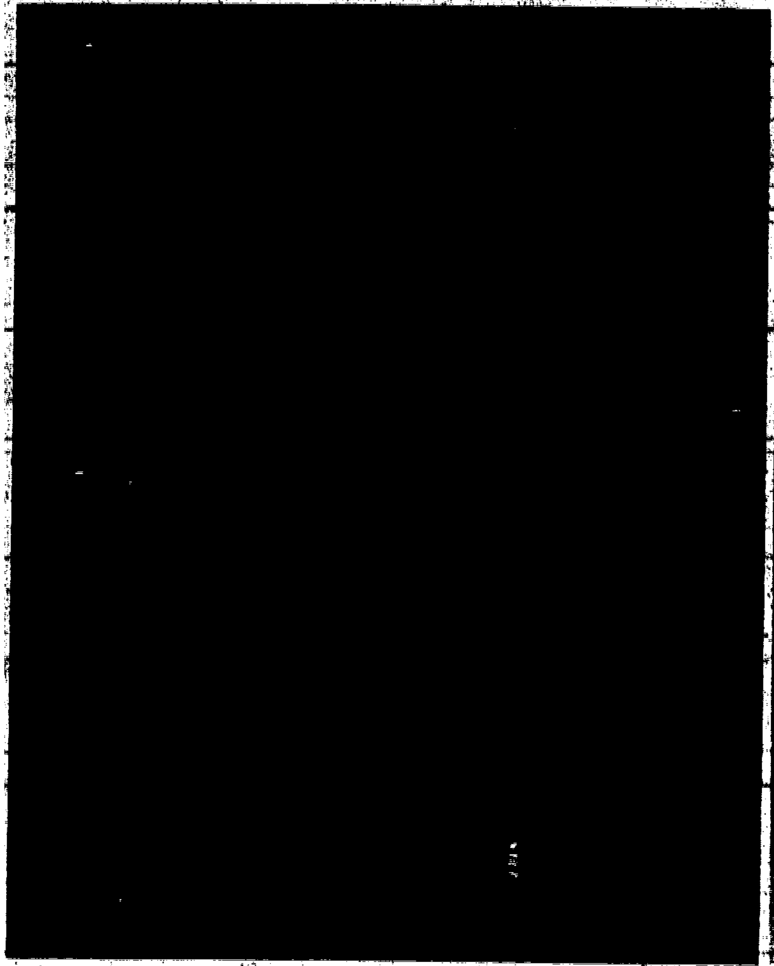
Satisfactory performance

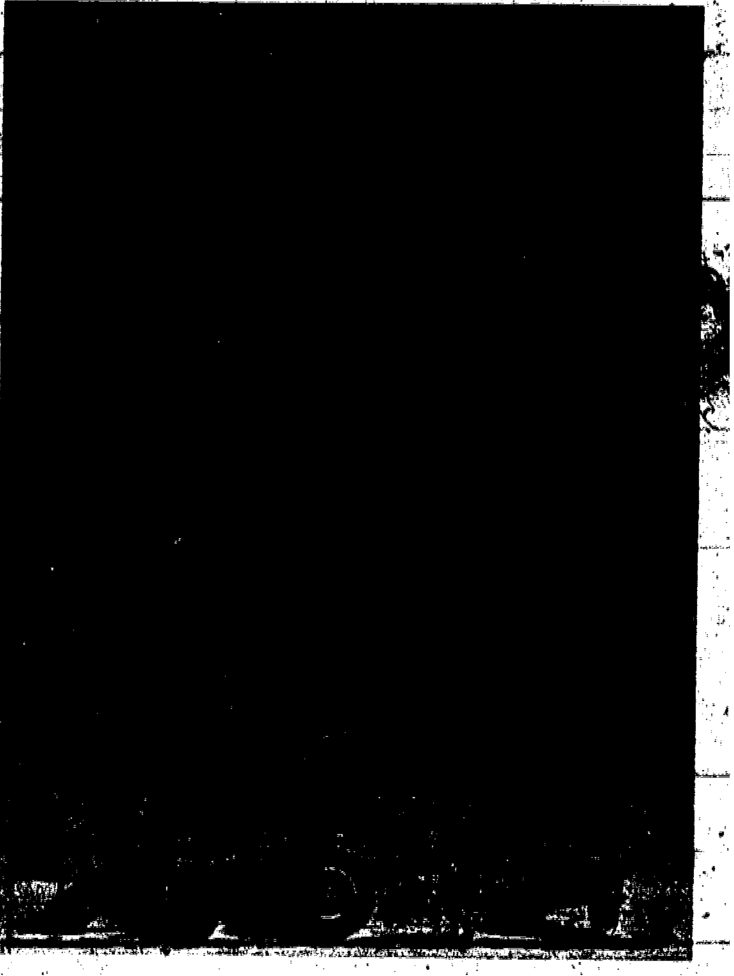
All things considered, "performance has been more than adequate for the intended job despite some adverse conditions," he says. These conditions included high winds, an unfavorable mounting angle, and an early hour for maximum insolation (10:40 a.m.).

During the winter, the system operates from about 7:30 a.m. through 3:30 p.m. The window collector maintains a respectable delta-T of about 60: When outside temperatures are in the teens, room air (in the sixties) is heated to nearly 120 degrees as it moves through the collector at 120 cfm.

For $5, Des Chenes is offering detailed plans and instructions for this system; for free, he'll answer specific questions that are accompanied by a self-addressed, stamped envelope. Address inquiries to John Des Chenes, 21 Dale Dr., Hinsdale, N.H. 03451.

kilowatts from the sky





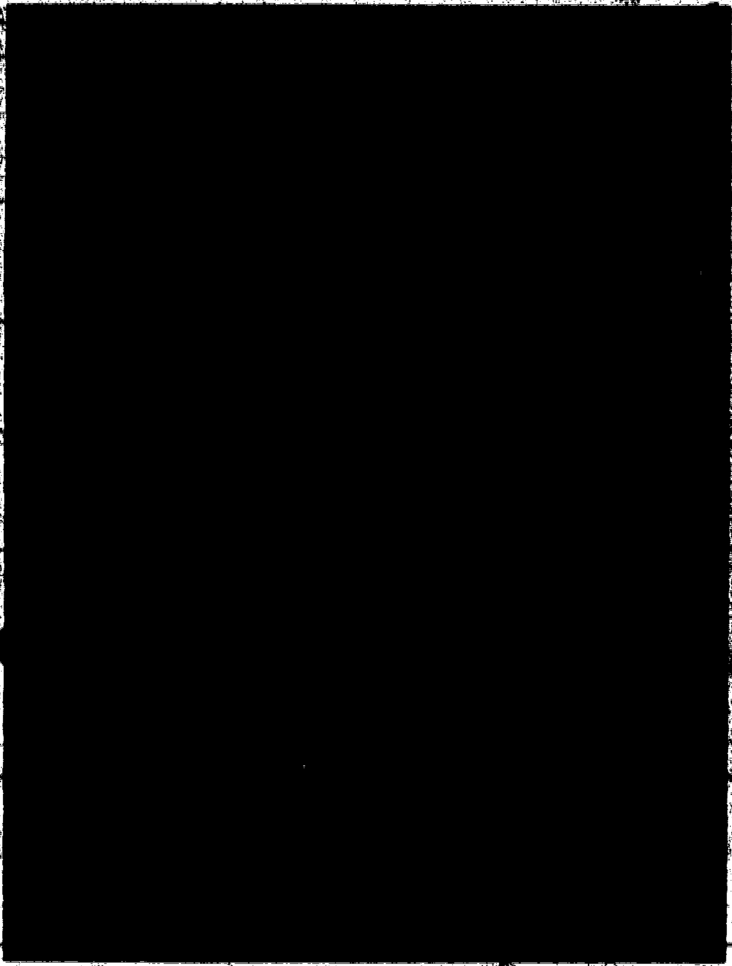
Left: *Ancient Egyptians worshiped a sun god.* Above: *Greeks focused the sun's rays to burn the sails of Roman ships.* Below: *An engraving of a "sun machine" used in the 18th century to melt metals.*

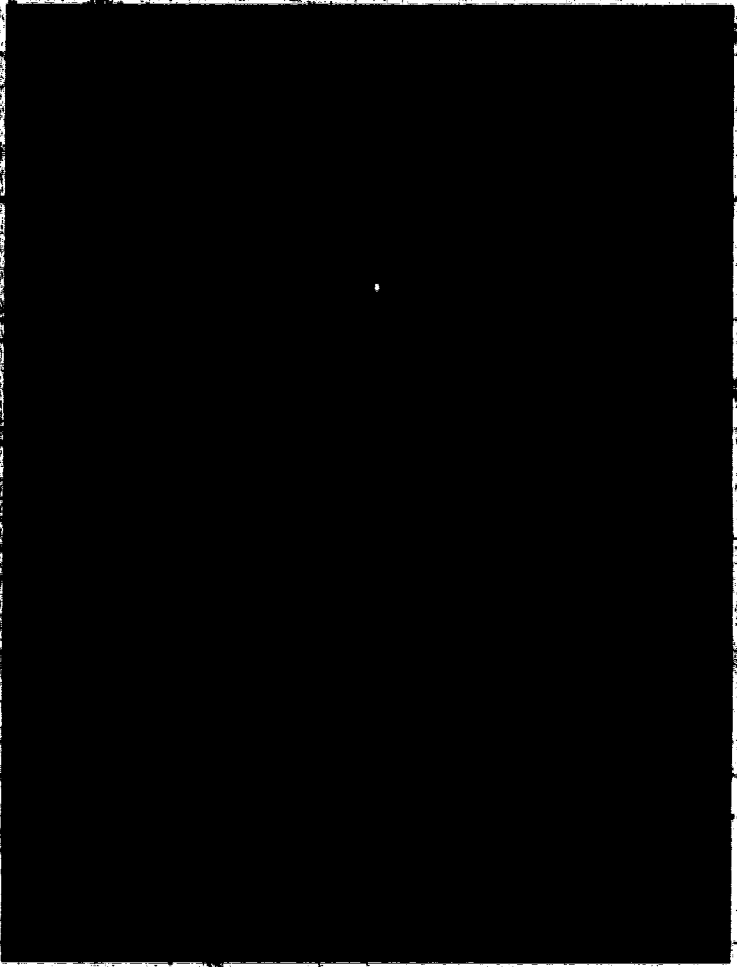
Clamber up a ladder to Harry Thomason's peculiar roof in a suburb of Washington, D.C. Look over the research facilities at General Electric's Valley Forge Space Center in Pennsylvania. Stand on a remote and weather-assaulted oil platform in the Gulf of Mexico. From the activity in these places and at other sites around the world, you'll begin to get the feeling that the phenomenon called solar energy is beginning to move from inventor's fantasies to growing practical use.

There are several important reasons why conditions now begin to appear favorable for solar energy. Among them are the gradual depletion of fossil fuels, a rapidly improving solar technology, a boost in the Federal government's interest and funding, an expanded research effort by universities and by companies such as Exxon. Finally, the public is becoming increasingly aware of solar energy's potential for saving fuel once the price of solar equipment can be reduced.

Of course, the idea of putting the sun's energy to work has always intrigued man. After all, the sun's radiation is responsible for all activity on this planet, from making the wind blow to creating fossil fuels. And from mankind's earliest existence, the sun's rays have been used in simple ways—to preserve meats and fruits by drying; in the growing of crops; to make cliffside dwellings and other homes

The sun's rays shower us with energy that scientists and engineers are putting to work. Exxon's solar cells are part of the action.





The prehistoric cliff dwelling of Arizona Indians made "passive" use of the sun for heating. Right, *at Odeillo solar furnace in the French Pyrenees, mirrors concentrate sun's rays to produce ultra-high temperatures.*

more livable. Today it is technically possible to use solar energy for many purposes, from heating or cooling homes and offices to providing power for entire cities, though costs are still high compared to that of conventional equipment. Surveying the staggering potential of solar energy, *Fortune* magazine recently speculated that power from the sun could become the "biggest economic development since the automobile."

Actually, we got off to a good start years ago in our quest to convert the sun's rays to our own purposes. The basic elements of many of today's solar devices—furnaces, concentrators, collectors, mirrors—were invented in the 1800s. But then came the more efficient use of wood and coal, and the discovery of oil and gas.

by PETER BRITTON

The predicted glories of solar energy were never achieved. Not surprisingly, cost and convenience had won.

However, men and women who firmly believed in solar energy quietly continued working to develop its use. From time to time there were significant attempts to promote it. During the Truman administration, for example, government spokesmen predicted that 13 million solar-powered homes would be available by 1975 (not far from the present administration's prediction for the year 2000). However, solar technology was still too expensive and research remained for the most part in the home workshops of a number of persistent inventors and in a few university and industry laboratories. Using the sun to heat or cool homes made sense to a small band of visionaries, and as a result a handful of homes around the country have for decades been using solar energy to augment conventional heating systems. In some cases, heating bills have been cut by more than half.

But these few working examples seemed gimmicky to most people. Who needed a Rube Goldberg contraption of water pipes, fans, rocks and glass plates on or under one's house? Then came the American space program and solar energy acquired both respectability and a surge in research funds. Space vehicles required lightweight, reliable, on-board energy sources for communications, guidance and other systems. The answer proved to be a device that was invented in the early 1950s at Bell Laboratories—the silicon solar cell.

The featherlight device designed for space vehicles converted sunlight directly into useful, work-performing electricity. No fuel was needed, there were no working parts, no maintenance was required and there was no pollution. While these solar cells were extremely expensive, they started people thinking of other, more down-to-earth applications.

The dramatic rise in the price of crude oil in 1973-74, coupled with a growing awareness of the truly limited nature of fossil fuels has caused governments and industry to look intensively for new fuel sources. The sun, with its awesome potential of limitless, free and clean energy, may help answer that need.

Each year the sun bathes the United States alone with over 600 times more energy than we now use, in the form of radiant energy. On a clear, sunny day at noon, the sunlight that strikes, say, a square meter of sod near Washington, D.C., can be made to produce a constant output of 1.5 horsepower or about 1.2 kilowatts of electricity. (The output varies with latitude, elevation above sea level, season of the year, pollution, time of day, surface reflectivity and cloud cover.)

Two basic methods can be used to convert sunlight directly into heat or electricity. In one, sunlight is gathered in "collectors," or concentrated by the use of mirrors to heat fluid or air. The second method uses photovoltaic devices such as silicon cells to produce electricity directly from sunlight.

According to estimates developed by some energy industry researchers, space heating and cooling account for about 17 percent of the nation's total fuel bill, hot water about 4 percent. Thus the savings in the use of other energy could be substantial. One estimate is that if 10 percent of new homes were to get three-fourths of their heating requirements from the sun, the equivalent of 102 million gallons of oil per year would be saved.

The simplest way to use solar energy for heating homes is the "passive" building in which construction materials are chosen to encourage or inhibit heat retention. Special curtains, double-paned glass, dark southward-facing walls and even water-filled drums are among the devices used for these purposes.

"Passive" homes may obtain up to 30 percent of their heat from the sun, but they can be too warm on very bright days or too cold after several cloudy ones. The more efficient solar homes use so-called flat-plate collectors of various kinds.

Dr. George Löf, of Colorado State University, has been involved in experiments with solar energy since 1941. For the past 18 years his Denver home has been one-third warmed by a simple hot-air-collector system which he says has never required maintenance and has cut heating bills considerably. Dr. Löf is also vice president of a firm which has provided some 50 Denver area buildings with improved solar systems that supply up to three-quarters of their heating and hot water needs.

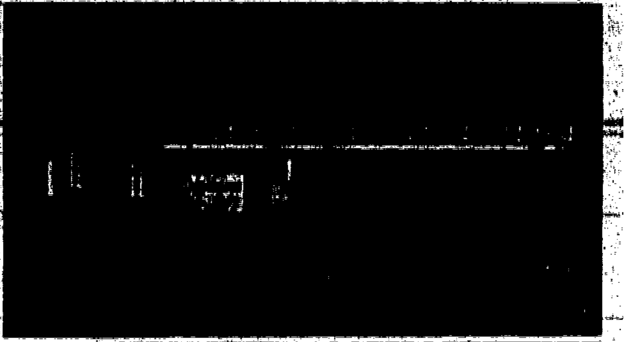
Another solar pioneer, Dr. Harry Thomason, has invented a slightly more complicated but, he says, less expensive system which uses water instead of air to store the sun's warmth. A 60 by 15-foot array of solar collectors is mounted on the roof of his Maryland home. When the sun shines, rainwater that has been collected and stored is warmed as it quietly trickles down through the system to heat the house below.

Thomason's 30 solar collectors face south and are tilted to the sun at a 55-degree angle. The corrugated aluminum plate within each of these four by seven-and-one-half-foot boxes is painted black for maximum absorption of the sun's rays. The plate is backed by insulating material and the box is covered with window glass which traps the heat.

In Dr. Thomason's system, water is heated to 100 degrees by the sun's rays, then circulated to the cellar where it is stored in a 1600-gallon tank surrounded by 50 tons of egg-sized stones. Here the water will gradually lose its heat to the stones, cool to about 65 degrees and then be pumped to the roof again to collect more heat from the sun. Meanwhile, an electric blower circulates air through the stones and this warm air is pumped into rooms through ceiling-level slits in the walls. Cold air is drawn off via floor-level slits and reheated.

Thomason's system, like Dr. Löf's and others, is thermostatically controlled and connected to a back-up oil, gas or electric furnace in case of prolonged cold or cloudy spells. All in all, the system is simple, quiet, efficient—and, according to Thomason, by saving roughly $350 a year in oil and electric bills it has paid for itself in seven years.

There are now some 187 solar homes in the United States, with another 300 under construction and the move into solar power is beginning to pick up some momentum. While interest in solar-powered homes mounts, the high initial costs of such systems and the fact that solar homes also must have backup conventional heating systems has acted as a brake on the rapid expansion of the solar industry. In addition, legal questions such as "the right to light"—whether one can legally block another's access to sunlight—along with zoning, building codes, aesthetic, environmental and other issues remain to be resolved. Nevertheless, the U.S. Department of Housing and Urban Development recently announced a grant

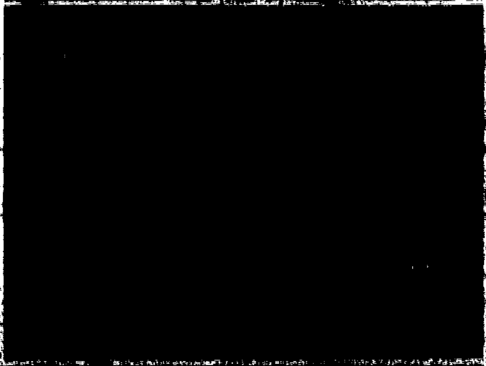


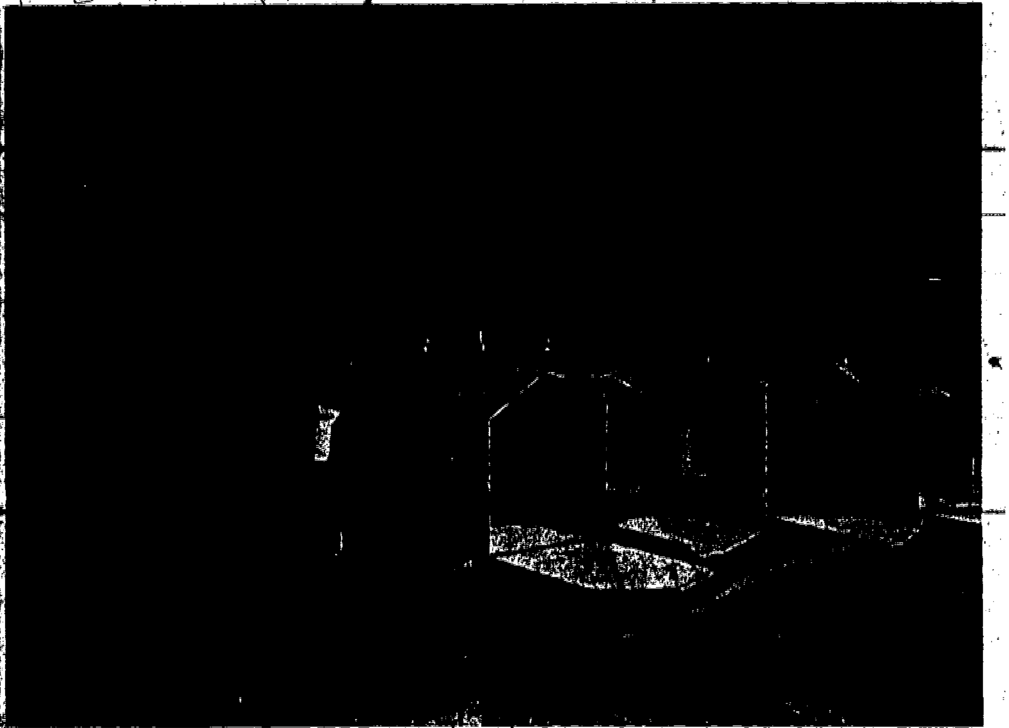
Clockwise from top left: *In the early 1900's, focusing mirrors concentrated the sun's rays on a boiler to power a steam engine that pumped water in Egypt. In New Mexico, solar concentrator uses sun's rays to generate steam for industrial applications.*

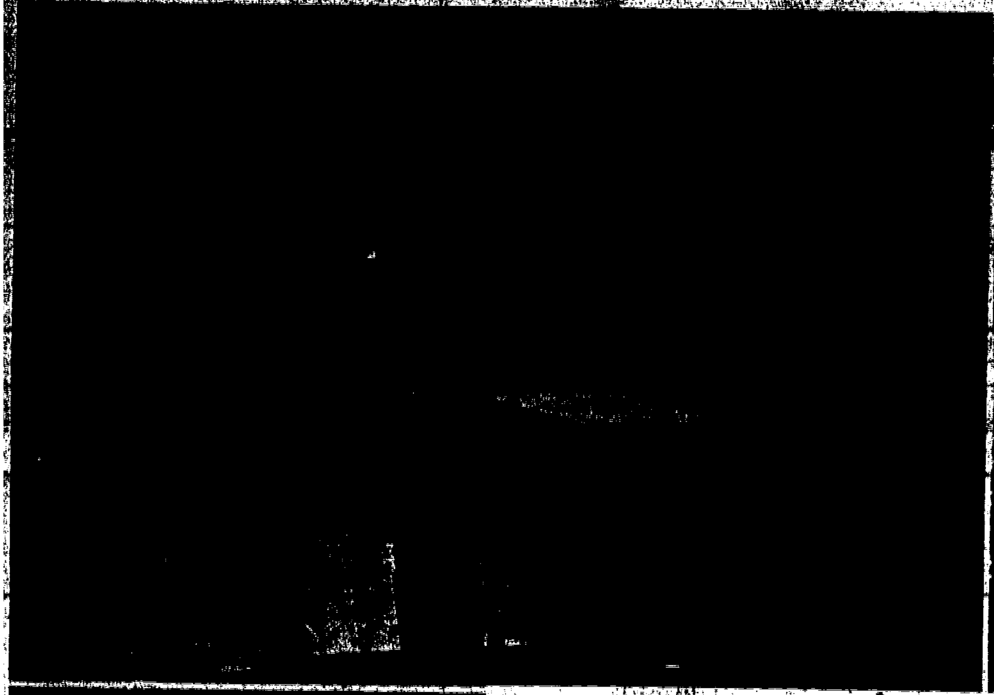
At Dunkirk, Md., home erected by Dr. Harry Thomason, solar panels c[illegible]he roof. Solar still in Symi, Greece, [illegible]rts seawater to fresh water. "Solari[illegible]ar-heated home in New Jersey, will [illegible] slanting roof covered with sod in[illegible]on.

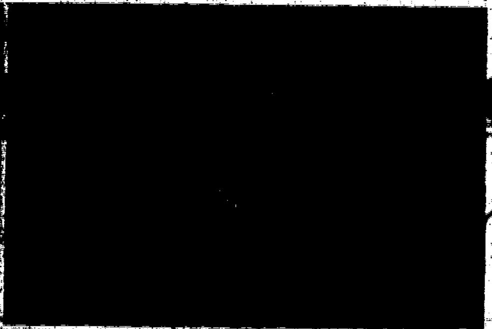
At Baer house in New Mexico, a wall of water-filled drums stores sun's heat. Another New Mexico home combines cooling adobe construction with solar cells that gather heat. In Kelbaugh home in Princeton, N.J., the plastic facade traps heat.

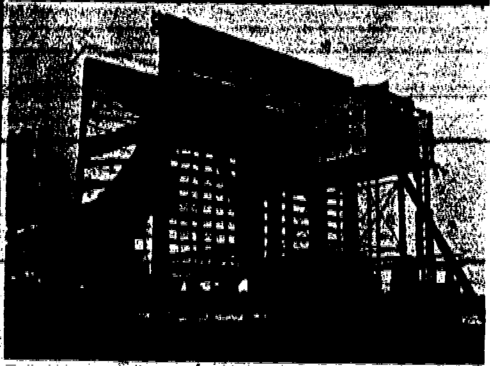
Solar collectors on the roof of an Atlanta elementary scho[illegible] provide part of its energy. Scientist Henry Hunter experiments with a black, waterfilled plastic bag on balcony of his Pleasantville, N.Y., house. Bag absorbs sun's heat, pipes circulate hot water.

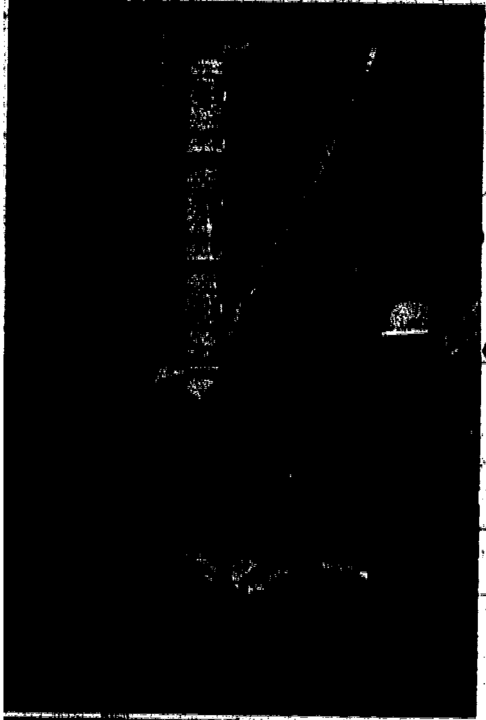










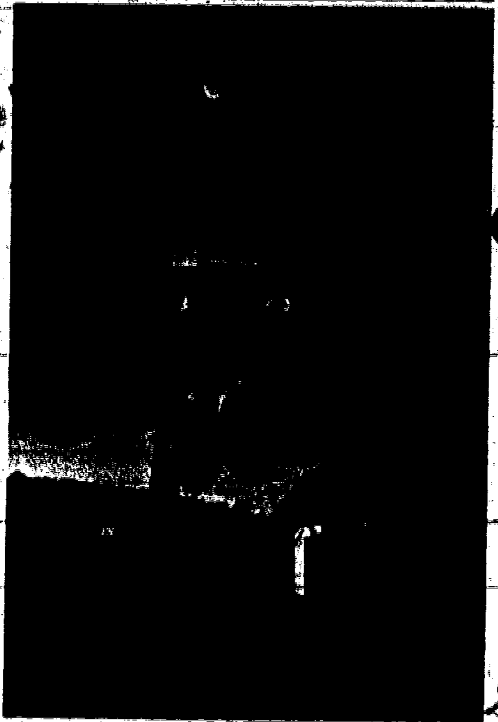


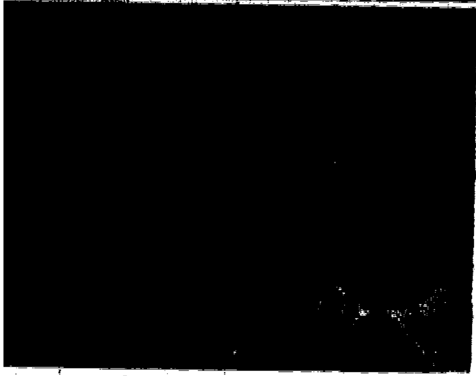
Photographs, clockwise from top left:
A giant parabolic reflector at the Odeillo solar furnace in France contains 9500 mirrors which focus the sun's rays on a surface in the facing tower. Roof-top solar panels heat homes in Israel.

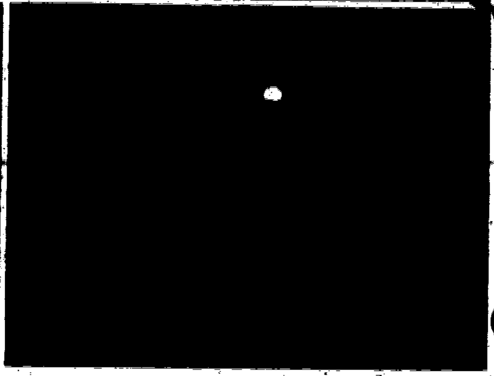
A solar furnace at White Sands, N.M., operated by a U.S. Army laboratory, tests missile components at temperatures up to 5000 degrees Fahrenheit. At a railroad crossing in Rex, Georgia, a solar array (rear) powers warning lights and bell.

Energy-giving sun sinks over Manhattan. At Exxon Research and Engineering laboratories, scientists use the sun's rays to decompose water by photolysis. An ER&E engineer displays a photovoltaic cell which generates electricity directly.

On an Exxon production platform in the Gulf of Mexico, technicians install a solar panel that will transform the sun's rays into electricity to be stored in the battery below the panel. The battery will power the foghorn in the white tower at rear.







of $1 million to install solar heating and cooling systems in 143 new and existing residential buildings in 27 states to test the practical application of solar power under a variety of climatic conditions.

In another step forward, Owens-Illinois has come up with a glass tube collector that it says can deliver temperatures of over 300 degrees at the same cost as the present flat-plate collectors but would take up only half the space. A number of smaller firms also offer technologically advanced flat-plate collectors, among them Day Star Corporation of Burlington, Mass., a young company in which Exxon has an investment.

These flat-plate collectors already on the market now are efficient enough for a substantial percentage of space heating needs, and the earliest large-scale applications are likely to come in shopping centers, schools and similar structures. Indeed such equipment is presently being utilized in an elementary school demonstration in Atlanta, Ga., providing 60 percent of the cooling, 50 percent of the heating and 80 percent of the hot water.

Widespread use of flat-plate collectors in this field would mean assembly-line production which would lower costs to a range that the average homeowner could afford. Consequently, some authorities foresee impressive growth. Dr. Peter Glaser of Arthur D. Little, Inc., the Cambridge, Mass., research firm, predicts that solar "climate control" equipment may be installed in as many as [illegible] million buildings by the year 2000.

A different kind of solar energy system, known at least since the days of Archimedes, concentrates the sun's rays by various means. The Greek mathematician allegedly set fire to an attacking Roman fleet in the harbor at Syracuse in 212 B.C. by using large metal reflectors to concentrate the sun's rays on the ships' sails. Centuries later, the French chemist Antoine Lavoisier aligned two lenses in such a way as to concentrate these rays and melt metals at temperatures of over 3,000 degrees Fahrenheit. In the 1950s, another French researcher, Felix Trombe, built a spectacular solar furnace at Odeillo high in the Pyrenees for use in materials research, smelting [illegible] solar studies. This arrangement of hundreds of mirrors, with a parabolic reflector forming the facade of a seven-story laboratory and a furnace as the focal point, [illegible] temperatures of 6,000 degrees F. that [illegible] burn through steel in a trice.

The most ambitious proposal using the concentration principle is the so-called "power tower." It would consist of a 1500-foot-high tower topped by a rotating boiler, with large mirrors circling its base ([illegible] versions on railroad flatcars) to concentrate the sun's rays continuously [illegible] boiler. The steam produced would [illegible] turbines to produce electricity. The [illegible] being studied at the University of [illegible], and in the Soviet Union, among other places.

Ultimately, perhaps the most useful solar energy device [illegible] the photovoltaic cell which turns sunlight directly into electricity. The cost of the cells, most of which are currently made from silicon, is dropping, and they can produce electricity today at a price that is one-tenth that of flashlight batteries. (Silicon is a non-metallic element widely available in nature.)

Among the companies producing silicon cells is Solar Power Corporation of North Billerica, Mass., a subsidiary of Exxon Enterprises, Inc. From its inception three years ago, Solar Power Corporation has concentrated on one aspect of the industry: photovoltaic devices for supplying electricity for terrestrial use. The new company has rapidly become one of the leaders in the business and its solar arrays are currently powering communications devices in the U.S., Italy, Ethiopia, Australia, New Guinea and Fiji.

Solar cells on one's roof may someday directly power the lights and the television set. But no one can predict when, or what such a product would look like. Meanwhile, today's configuration is a thin, round wafer of silicon mounted in tough silicone rubber, facing sunward and connected to storage batteries. One system of this kind is in action in the Gulf of Mexico. There, Exxon Company, U.S.A. has installed arrays of such cells on several off-shore oil production platforms—unmanned stations that need reliable power sources for their fog horns, lights and warning bells. It is typical of many current uses of solar cells: a remote area where conventional power doesn't exist and equipment is hard to reach and service. Other examples are radio relay stations on mountain-tops, educational [illegible] isolated villages and warning sig[illegible]ng lonely railroad lines.

[illegible]xon Research and Engineering [illegible] in Linden, New Jersey, scien[illegible] answers to a host of so[illegible]blems: developing new [illegible] produce electricity [illegible] sunlight; developing [illegible] that can be recharged using light; [illegible] photolysis, or breaking down water into its elements under light and a catalyst to produce hydrogen for fuel.

Perhaps the grandest scheme of all for solar energy may take shape far out in space. Scientists and engineers have proposed that 20-square-mile satellite solar power stations be erected some 22,500 miles up in a stationary orbit. Through a combination of solar cells and mirrors, these stations would transform solar energy into electricity, then transmit it to earth in the form of microwaves where it would be reconverted to electricity. According to one estimate, a 20,000-ton station of this kind might provide 15 billion watts of continuous electrical power a year—just about enough for the needs of a city like New York in the year 2000. This herculean concept is currently being studied by the U.S. Congress.

Many experts think that solar energy will eventually combine with nuclear fusion to fill much of the world's energy needs. Others think the sun could do the job by itself. But whatever the outcome, it would appear that the use of solar energy in some form is here to stay.

Says A. L. Shrier, manager of solar energy projects for Exxon Enterprises: "The rate at which solar energy establishes itself will depend on the cost to the consumer. And the cost is coming down. With a lot of work and a bit of luck, the United States may be supplying up to 5 percent of its energy requirements from the sun by the year 2000. I think it can—and will—be done." ■

Power from the Sun is safer and easier to come by.

Soft and Hard Energy

by Nicholas Wade

When 19th century British inventors discovered the power of steam, they applied it to pumping water and propelling locomotives. When Hero of Alexandria made the same discovery in the first century AD, he too applied it to a characteristic preoccupation of his times—the opening and closing of temple doors. One can make the right discovery at the wrong time.

Is the same true of solar energy? Sun-worship is enjoying a new dawn in the United States. Wednesday, May 3, has been designated Sun Day by some who think solar energy should loom larger in the national consciousness. It is no accident that Sun Day's conceiver, Denis Hayes of World Watch, was also the organizer of 1970's Earth Day; environmental and anti-nuclear groups are among the chief acolytes of solar energy, and they have a large and expanding following. Their message has undeniable appeal: sunlight, could we but harness it, contains far more energy than the amount we now so painfully acquire from fossil fuels, and unlike them, it is inexhaustible, non-polluting, free, and in total harmony with the arrangements of a democratic society.

Conventional wisdom, spearheaded by the nuclear and electrical industries, and prevalent in most parts of the Department of Energy, holds that solar energy may become an important source in the next century but is pie in the sky for now. Even if the technical problems are solved, the high capital cost of most solar energy devices will rule them out as serious competitors with conventional fuels for the foreseeable future.

The debate about solar energy is at its root an intricate exercise in technical and economic forecasting. But it is also enriched with themes of potent social and political import. Proponents of solar energy are wont to stress that sunlight is free. The suggestion, a touch demagogic, is not wholly true. Nicholas Georgescu-Roegen, whose book *The Entropy Law and the Economic Process* (Harvard 1971) established a theoretical framework for inserting the sun into economics, is careful to describe solar energy as an *almost* free good—to catch it, you need to own land. But what has become the political manifesto of solar energy appeared in the October 1976 issue of *Foreign Affairs* in an essay by physicist Amory Lovins of the Friends of the Earth.

Lovins's theme is that there are two paths the United States could take over the next half century in meeting its energy needs. The hard path relies on rapid

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expansion of centralized high technologies, typically designed to generate electricity in large power stations. The soft path means developing renewable energy sources—usually smaller in scale and of less demanding technical quality. The two paths, Lovins warns, are mutually exclusive: if we take the hard path and it fails, the soft path may be foreclosed.

Courtesy of Bettmann Archive

Choice of path will influence the structure of society because of the contrasting nature of "hard" and "soft" energies. Soft energy technologies, says Lovins, differ from hard in these ways:

- They depend on renewable energy flows such as sun, wind and vegetation.
- They are diverse, so that energy supply comes from numerous small sources tailored to particular needs (such as solar heat collectors on buildings) instead of from large central power stations.
- They are easy to understand and use, not demanding esoteric skills such as nuclear engineering.
- They are matched in scale and geographic distribution to end uses, meaning that where there are strong, steady breezes one builds windmills instead of buying electricity from far away. (Half your electricity bill goes for distribution costs.)
- They are matched in quality to end uses. High grade forms of energy such as electricity are very costly, yet are often put to purposes (such as space heating) for which low grade energy (coal, oil, gas) would be adequate and far more efficient. A power station must use three units of fuel to get one unit of electricity, for the other two are lost as waste heat.

The hard energy path, to summarize Lovins, loses on both costs and risks. It means investing billions of dollars in new mines, power stations and enrichment plants, gambling on the successful development of a few risk-laden high technologies, and imperiling the environment with fossil fuel by-products, waste heat, and the threat of climatic change. The soft path depends on developing a diverse assortment of low technologies, all of them environmentally gentle. The hard path will lead to nuclear proliferation abroad, and at home to a dirigiste autarky brought about by the need to prevent terrorist diversion of nuclear material. The soft path will produce technologies which are suitable for poor and rich countries alike, and compatible with an open, pluralistic, democratic and decentralized society. Take your choice, says Lovins, and remember that the wrong one is irrevocable.

How viable is the soft energy path? The technologies which seem at present to hold most promise include solar cells, windmills, solar thermal energy, and biomass fuels. To this list should be added two alternative technologies which Lovins, for one, does not consider to qualify as soft: the solar power tower and the OTEC, a Leviathan-sized machine that works on the temperature difference between the surface and bottom waters of tropical seas.

Solar Cells. Arrays of solar cells are familiar as the wing-like panels that power satellites by converting sunlight into electricity. The satellite cells, however, are hand-made and sell at aerospace prices. A reduction to one-thirtieth of today's price is needed before solar cells can be brought down to earth. If the reduction is achieved, and if electric utility charges continue to edge up, solar cell arrays "would be able to generate supplemental electricity at prices competitive with electricity from other sources in wide areas of the country," says a June 1977 report from Congress's Office of Technology Assessment.

A price drop of this magnitude may not be as impossible as it seems. Solar cells are semi-conductor devices, and the industry expects that, just as in the case of hand calculators, the price of solar cells could plummet as soon as a mass market is established. Present day prices for certain terrestrial uses are already one-fiftieth of those that prevailed a few years ago in the space market.

Solar cells are made out of the rock-common element silicon, which is first purified and then lightly doped with certain impurities that make it into a semiconductor of electricity. Light falling on the cell is converted into electrical energy. Attaching metal contacts and assembling the cells is at present done mostly by hand; automation is one step necessary before solar arrays find a place on rooftops.

Windmills. Since the 1850s, six million windmills have been installed in the United States. The windmill is not yet ready for modern resurrection, but its time may come. A large experimental windmill built by the Department of Energy started turning in Clayton, New Mexico last month and is expected to generate up to 15 percent of the electric power used by the town's 3000 residents. The department reckons that windmills are within a factor of between two and four of being economically competitive. Small windmills for home electric use are commercially available but so expensive as to be attractive only to those whose houses are remote from any electric grid system. As with all solar energy, a storage system is necessary unless the device is used just to supplement existing power supplies. There is a broad potential base for wind power in the United States: many regions receive almost as much wind energy per year as they do sunlight.

Biomass. Lovins believes that by 2000 AD, the fuel needs of the entire American transport system could be met by alcohol produced from plant material. His calculations are not universally accepted, but there is a future of some kind to be discovered in what energy technologists call biomass conversion. Some forecasts suggest a large market soon for alcohol fermented from sugarcane, sorghum, or spoiled corn. The alcohol could compete directly with industrial alcohol made from ethylene, or be blended with gasoline and used as a motor fuel, "gasahol." Other schemes include producing methane gas from algae grown on sewage waste. The economics of such proposals remain uncertain. Even if biomass fuels become competitive with fossil fuels, their cultivation will not be sylvan or bucolic, warns a recent Mitre Corporation report: "The proper analogy is a logging forest and pulp mill."

Solar thermal energy. The least glamorous of all solar devices and probably the nearest to the marketplace, solar thermal systems can be used to produce steam in industrial processes, generate electricity in small installations, and supply heat for homes and offices. Simple flat-plate collectors can trap enough sunlight for residential space and water heating. Where temperatures above 100°C are needed, sunlight can be concentrated by mirrors steered to track the sun's motion. A large potential market for solar thermal energy exists in the food, textile and chemical industries where copious amounts of intermediate temperature heat are used. Most of the equipment needed for solar thermal heating seems already to be available, although further improvements could be made on the heat engines which convert the heat into shaft power to drive a generator, air conditioner or whatever. According to the Office of Technology Assessment, solar hot water heaters for domestic use are already competitive with electric water heaters, and solar equipment will soon be a good bet for fulfilling the heating and hot water needs of large buildings.

Power towers. The power tower, the pride of the Department of Energy's solar program, is a 100-megawatt device which will consist of a boiler perched on a 1000-foot tower at the focus point of a field of sun-tracking mirrors. Design of the boiler is expected to be problematic; it is too early to estimate the costs at which the system can deliver energy.

OTEC systems. Vast underwater towers that operate on the temperature difference between top and bottom water, OTEC systems are attractive because they could draw on an inexhaustible source and be able to work 24 hours a day. Thermodynamic laws decree, however, that since the temperature difference is relatively small, the efficiency of the system will be as slight as 2 or 3 percent. Any slippage in performance, such as might be caused by marine slime or barnacles, could put the whole system in the red.

There are many promising possibilities in the solar energy field, although most devices have a way yet to go both economically and technically before they can begin to compete with current sources. The market share of all solar energy devices will depend critically on what happens to the cost of conventional fuels. If, as some experts now believe, oil supplies remain adequate at least through 1990, the price of oil is more likely to stay stable and solar energy to stay uncompetitive. As for technical problems, it is not universally agreed that the Department of Energy is doing as well as it could to bring solar energy to market. Environmentalists regard as too niggardly the $300 million a year allotted by the department to solar energy. The heart of the agency is the old Atomic Energy Commission and some observers see signs that the hard path methods used to develop nuclear power are being applied, with singular inappropriateness, to the shaping of solar energy systems. The department's solar research program "has emphasized large central stations to produce solar electricity in some distant future and has largely ignored small solar devices for producing on-site power —an approach one critic describes as 'creating solar technologies in the image of nuclear power,'" concluded Allen Hammond and William Metz in a recent series of articles in *Science*. "The program contains virtually no significant projects to develop solar energy as a source of fuels and only modest efforts to exploit it as a source of heat. The massive engineering projects designed by aerospace companies which dominate much of the program seem to have in mind the existence of the utility industry—rather than individuals or communities—as the ultimate consumer of solar energy equipment."

The general argument for switching to solar energy is compelling. The earth's outstanding recoverable reserves of fossil fuels are estimated to be the equivalent of two weeks' sunlight. Our consumption of fuels (and other minerals) is done at the expense of future generations; once depleted, mankind's dowry of low entropy materials can never be replaced.

Whether the transition to solar power and its kin is to take place in the next decade or after all the oil has gone is a matter not of values but of technics and economics.

Solar Energy Research: Making Solar After the Nuclear Model?

A point about solar energy that government planners seem to have trouble grasping is that it is fundamentally different from other energy sources. Solar energy is democratic. It falls on everyone and can be put to use by individuals and small groups of people. The public enthusiasm for solar is perhaps as much a reflection of this unusual accessibility as it is a vote for the environmental kindliness and inherent renewability of energy from the sun.

But the federal program to develop new energy technology is giving only belated recognition to solar energy's special characteristics. Despite the diffuse nature of the resource, the research program has emphasized large central stations to produce solar electricity in some distant future and has largely ignored small solar devices for producing on-site power—an approach one critic describes as "creating solar technologies in the image of nuclear power." The program contains virtually no significant projects to develop solar energy as a source of fuels and only modest efforts to exploit it as a source of heat. The massive engineering projects designed by aerospace companies which dominate much of the program seem to have in mind the existing utility industry—rather than individuals or communities—as the ultimate consumer of solar energy equipment.

This is the first in a series of Research News articles examining recent developments in solar energy research.

One consequence of this R & D emphasis on large-scale, long-range systems is to distort economic and policy assessments of solar energy based on the current program, both within the Energy Research and Development Administration (ERDA) and in higher levels of the government. Indeed, the potential of solar energy is still regarded with skepticism by many government energy officials and publicly discounted by spokesmen for oil and electric utility companies. Funds for solar research are leveling off, because of cuts made by the outgoing Ford Administration and confirmed, with minor overall changes but some shift in emphasis, by the Carter Administration. Agency officials concede that even the present federal program—representing an investment less than one-half of that for new coal technologies and a small fraction of that committed to the nuclear field—has survived only because of the immense popular appeal of solar energy and consequent pressure from Congress.

In contrast to this official skepticism is the virtual explosion of optimism and activity elsewhere. Dozens of pieces of proposed solar legislation and hundreds of companies now manufacturing solar components reflect this interest. The number of solar-heated houses built in the United States has doubled approximately every 8 months since 1973, and the rate shows no signs of slackening. The rapid buildup of a fledgling industry has been matched or even exceeded by a staggering rate of technical innovation in designs for solar equipment and in research on advanced methods for capturing and using solar energy. Measured by the number of new ideas or the rate of progress, solar energy has become the hottest property and the most sought-after action in the energy field. The burden of criticism from the solar energy community and from independent analysts is that the federal program has lagged rather than led many of these developments and that it has directed its research toward goals that betray a lack of understanding of the solar resource.

Coming to Grips with Solar

The government's difficulty in coming to grips with solar energy is understandable because the solar program was born, in an institutional sense, only about 5 years ago. The early work on solar energy was scattered among various government agencies, but much of it was an outgrowth of the National Aeronautics and Space Administration (NASA) effort to find practical spin-offs from space technology. After the 1969 Apollo moon landings, four different NASA labs began to do modest amounts of solar energy research. In 1972 the National Science Foundation (NSF) became the lead agency for solar energy research, which was funded at only $2 million per year. Many of the early program managers came from NASA and much of the contracted research went to aerospace companies.

In early 1975, all the solar research programs were shifted from the NSF, which has not been organized for commercial technology development, to the newly formed Energy Research and Development Administration, where solar was cast into competition with the nuclear breeder, the government's newly invigorated coal program, and the growing program for fusion. In its first 2 years the ERDA solar program was greatly understaffed and overworked—at one time 60 percent of the mail for the entire agency concerned solar energy. But in spite of institutional handicaps, the program grew rapidly because Congress authorized large increases in the solar research budget—as much as 80 percent above what the agency officially requested.

The program under ERDA moved into a mode of design, construction, and testing of various types of solar power pilot plants on an aggressive timetable. Feeling pressure to build up the solar program rapidly, ERDA delegated a large—some critics would say dominant—role to its national laboratories and to various NASA laboratories. The different subprograms were evaluated in a series of "mission analysis" studies, largely performed by aerospace contractors, and new priorities were set. Much of the evaluation was based on the capability of various solar technologies to approach base-load electric power supply—under the assumption that anything else would fall short of a major contribution. During this crucial period of solidification, the program had no regular review by an outside advisory board and there were no congressional oversight hearings. One of the strongest outside influences on the shape of the program, according to well-informed observers, was the utility industry.

Today, government solar research is a $290 million effort spread among four subprograms for electric applications, one for fuels, and two for heating, cooling, and related direct applications, with a professional staff of about 70 persons. In fiscal 1978, the program recommended by the Carter Administration will grow only modestly to $320 million. Because the various solar technologies are generally unrelated to each other, there is not a great deal of overlap between the research bases needed for the subprograms. The result is that the different solar options are at an even greater disadvantage vis-à-vis other energy programs than the total solar research budget would indicate.

The largest allotment of ERDA funds and staff resources has been for solar electric technologies. The concept which the utility's research arm—the Electric Power Research Institute—sees as the most likely candidate for central electricity generation is the power tower, a system with a boiler on a high tower heated by the sunlight reflected from a field of hundreds or thousands of sun-following mirrors. The power tower with its related solar thermal systems is still the leading subprogram in dollar priority—$79 million in fiscal 1977. Next is research on photovoltaic power systems—an effort to develop low-cost versions of the silicon cells used on space satellites for converting sunlight directly to electricity. Wind-power research, although it is the solar electric technology closest to being economically competitive, receives only about 8 percent of the solar budget. Approximately 5 percent goes to develop methods of extracting energy from the small temperature differences between surface and deep seawater—a concept usually referred to as OTEC (ocean thermal energy conversion) and conceived to produce electricity or perhaps an energy-intensive chemical in a huge floating plant that would provide about 200 megawatts of power. Still less money presently goes to the solar resource that could be most versatile of all—plant matter or biomass, which can be converted into either heat, fuels, or electricity. ERDA officials are generally agreed that biomass is one area in which they have yet to get a strong and coherent program under way.

The solar heating and cooling subprogram is funded at $86 million at present and $96 million in the fiscal 1978 budget. Solar home and hot water heating is nearly competitive in some areas of the country already. However, the ERDA program has paid little attention before now to the benefits of passive solar heating—the capture of solar heat that can be achieved from a well-sealed south-facing window as opposed to a rooftop solar collector used with a water or airflow system to carry the heat downstairs. Such systems are now widely thought to be capable of filling a large fraction of the winter heating needs in many areas at costs generally less than those of active systems.

As the Carter Administration prepares to shift energy research to yet another agency—the proposed Department of Energy—solar energy is still in search of a proper institutional home. Noting that skepticism of the solar program is one of the proper functions of ERDA's management, Henry Marvin, solar program director, nevertheless says that the program has been subject to tight controls by the agency's upper echelons and by the Office of Management and Budget. In his words, "Congress has been the corrective factor" in the growth of the program. According to Marvin, the solar program now has all the money it needs, "but we are still somewhat staff limited and travel-money limited—that has been the mechanism of OMB control." He foresees a program that may have already reached its broadest extent and will focus more narrowly as early decisions are made about solar hardware development projects in 1978 to 1981 and successful technologies are transferred to private industry.

Marvin is credited by several observers with having sought to limit the role in the program of the national laboratories which, he says, "are not natural stopping places" enroute to developing commercial technologies—and with having managed the program competently within the guidelines set by the agency.

Centralized versus On-site Solar

But critics believe those guidelines still reflect the narrow set of preconceptions with which the program began. One of these preconceptions is the preferred rôle of centralized energy systems. Several pieces of evidence suggest that the ERDA program has given inadequate attention to the issue of the appropriate scale for solar technologies and, in so doing, has failed to exploit the most promising characteristic of solar systems. A report recently issued by the Congressional Office of Technology Assessment (OTA), for example, points out that federal research on electric generating equipment of all kinds has been focused almost exclusively on a centralized approach and has neglected what OTA sees as a significant potential for on-site power production. The report—one of the most comprehensive studies of emerging solar technologies yet made—concludes that "devices having an output as small as a few kilowatts can be made as efficient as larger devices" and that on-site solar systems capable of generating electricity at prices competitive with those charged by utilities may be available "within 10 to 15 years." "Onsite solar energy," the report declares, "must be regarded as an important option."

The solar thermal subprogram provides an instance of how ERDA's choices of scale were established. Initially, the subprogram was conceived of exclusively in terms of central power stations, as large as possible. Charles Grosskreutz, an analyst with the engineering firm of Black and Veatch during the period when it was involved in the initial program analysis of power towers for ERDA, says that "everyone started by considering a 1000 megawatt size and quickly scaled it down to about 100 megawatts" when it became clear that the tower height and the land acquisition problem were impractical for the larger sizes. "To my knowledge," he says, "there are no good studies of the optimum size of these facilities." Little serious consideration appears to have been given to solar thermal generating facilities in conjunction with community-scale energy systems or biomass fuel refineries—applications for which the optimum size, according to Princeton University physicists Robert Williams and Frank von Hippel, will probably be much less than 10 megawatts. According to Marvin at ERDA, "it may well be that 10 megawatts is the unit size for the power tower—we used 100 megawatts for our calculations."

Likewise, the wind-power program, according to early program documents, did not look carefully at the prospects for improved versions of small wind turbines for distributed applications, or at the potential economies of mass production that might apply to small devices but not to large ones. Instead, the program plunged ahead to build a large, 100-kilowatt prototype as a first step toward a commercial size conceived to be as large as possible with the materials available—1.5 to 2 megawatts.

Williams and his colleagues point out that the ERDA solar program throughout concentrates its main efforts on the largest and smallest scales of energy production, but they contend that an intermediate size may turn out to be the natural scale for many solar technologies. Their analysis points to community-size systems, equivalent to a few hundred or a few thousand houses, as the most cost-efficient, in that they would allow storage of solar energy on an annual basis—something impractical for an individual house—and would also allow the coproduction of solar heat and electricity in a manner that would be impractical for large central power plants.

Other independent analyses have come to similar conclusions. The noted British radio astronomer Martin Ryle, in a study of the applicability of solar energy to that country, concludes that a distributed network of small wind turbines provides the best match of potential supply to demand and would be competitive with coal-fired or nuclear generating stations. Ryle concluded that windpower, used with storage systems, could provide a substantial part of the power needs of the British Isles.

Another criticism of the solar program is that its management has been unnecessarily restrictive. During the last 2½ years, while ERDA has directed the program, it has been guided by a management philosophy of "aggressive sequential" development. In practice, this has meant a policy of giving priority to one solar technology in each subprogram, such as the power tower in the solar thermal program, and pushing it to quickly develop hardware and test its feasibility. What the policy has ruled out—reportedly because of skepticism from the agency leadership and budget-cutting by the Office of Management and Budget—is the parallel development of competing concepts. It is, of course, possible that the best candidates were not chosen initially, but nevertheless a whole solar subprogram could be phased out because of poor performance by an ill-advised solar concept. In particular, features such as scale and type of application have been heavily influenced by the original choices for development, and there is considerable danger that values derived from those choices will be the ones on which engineering and economic evaluations of future support will be made. It is just such considerations that lead environmentalists to make the charge that solar energy is being "set up" to fail.

Commenting on the desirability of pursuing parallel concepts, Marvin says that "it is not clear that we would not be more productive if we could pursue multiple paths." But he believes that it would be disruptive, if not politically impossible, to stop existing programs. He says he has attempted to correct what may be imbalances by bringing in a new group of managers (two of whom just arrived this month), and by supporting some of the neglected options as secondary, follow-on efforts when the budget allows. For instance, the fiscal 1978 budget includes $8 million for small-scale windmills. Marvin notes, however, that "it doesn't gain us time lost."

Another problem with the solar program has been lack of flexibility, leading to too little integration of different solar technologies with each other and with the energy needs they might ultimately satisfy. Storage is a problem with many solar systems, but the program has given little attention to applications in which biomass fuels would provide the storage element, or in which the need for storage is obviated by using solar energy in conjunction with another energy source. Solar-coal and solar-hydroelectric systems offer tantalizing possibilities for combinations that could approach around-the-clock power, and there is some evidence that direct solar energy and wind energy might complement each other well. Little attention has been given to on-site application of photovoltaic and solar-thermal devices, in which the utility grid could be used as a buffer and thus storage would not be required. In addition, a generally acknowledged problem with the ERDA program is that its sharply divided subprogram structure has limited the development of systems that serve two purposes at once, such as total energy systems that produce both heat and electricity with a considerable improvement over the efficiency of single-purpose system. The program has only belatedly begun to look at projects that do not fall into any of the predefined categories, such as solar irrigation, which ERDA developed no sooner than did the state of Guanajuato, Mexico.

The organizational structure of the energy agency, moreover, appears to be at cross-purposes with many novel or noncentralized applications. The solar energy division, for example, is effectively prohibited from working on community-scale solar systems because the agency management has decreed community-oriented projects to be in the domain of the conservation directorate.

Cost is the stumbling block most often cited by solar skeptics, and there is no doubt that few of the solar options are competitive today. But current cost estimates are almost certainly deceptive, in the absence of a real market. Furthermore, no one really knows what the costs of small-scale systems will be because so little research has been done on them. The conventional wisdom at the solar program planning office is that, compared to electricity at current prices, wind generators are competitive today or within a factor of 2 of being competitive, biomass fuels are a factor of 2 to 4 away from a competitive price, ocean thermal power systems a factor of 4 to 5, power towers a factor of 5 to 10, and photovoltaics a factor of 20 to 40 away. The opportunities for price reduction among these different technologies are controlled by quite different factors, however. Even the technologies for which a market does exist—hot water heating, for example—do not yet benefit from the kinds of implicit subsidies enjoyed by most other energy sources or the advantages of mass production by a well-established industry.

Probably no question about solar energy is more controversial than whether it can become a major energy source in the near term or should be regarded (and funded) as a limited, long-range option. Assessments of this question tend to get swept up into what has become a highly polarized debate between environmental advocates and the defenders of coal and nuclear power—a debate whose terms are more nearly philosophical or ethical than economic. The one view holds that a transition to a predominantly solar economy is not only feasible but *necessary*—to avert climatic disaster from the buildup of carbon dioxide that would accompany massive use of coal, and to prevent the danger of nuclear warfare attendant on the proliferation of the plutonium economy. The other dismisses solar energy and holds that coal and nuclear are essential on the grounds that even if costs were to drop dramatically, it would still be many decades before enough solar-heated houses and solar power stations could be built to make any dent in this country's huge and growing appetite for energy.

But these tactical positions obscure a number of things that tend to argue the importance of solar energy on purely economic grounds, as well as some substantial problems. One of the key problems is that solar equipment tends to be capital-intensive, with high initial costs that are a deterrent to consumers unaccustomed to making decisions on a life-cycle basis. Another is that many existing institutional arrangements, from building codes to utility rate structures to federal tax policies, discriminate against unconventional energy sources. But some institutional barriers are being removed by legislation, and the prices of many solar components are already dropping sharply in response to steadily growing demand. It seems evident that the growth of distributed solar systems, for which equipment can be mass-produced, can be far more rapid than the growth of centralized power plants, which must be laboriously assembled in the field. Frost and Sullivan, a respected market research firm, predicts that 2.5 million U.S. homes will be solar heated by 1985. The government itself may become a major market for solar energy—a Department of Defense report done for the Federal Energy Administration estimates that a DOD market for up to 100 megawatts of photovoltaic devices a year may exist at the prices expected to prevail in the early 1980's.

Political fortunes may also play a role in determining the short- or long-term impact. Solar energy fared badly under a Republican administration. President Ford had many opportunities to attend solar project ribbon cuttings but did not do so. Under his administration, the OMB strenuously opposed and nearly gutted the major short-term elements of the government's solar energy program—the demonstration projects for solar heating, ERDA appealed to President Ford but, according to one observer, had the misfortune to argue its case during a week in which Ford was preoccupied with the Angolan crisis. In any case, the OMB position largely prevailed—a circumstance that apparently contributed substantially to the resignation of ERDA assistant administrator John Teem—and the proposed demonstration program, modest though it was, was drastically cut back.

The government program is having some effect—ERDA's work on photovoltaics and wind has stimulated some private investment. And quite apart from the government's program there appears to be a remarkable amount of momentum in solar thermal devices, wood burning stoves and boilers, and other components of a solar energy industry.

After 5 years of rapid but uneven development, solar energy is in need of reassessment. The present federal program has been as much the product of institutional happenstance and various technical predilections as it has been the product of coherent planning. In a broader perspective, the government policy under Republican administrations characterized solar energy as a long-term option comparable to fusion and the breeder, but in fact it has little in common with these potential leviathans. Solar technology is more diverse, and even the most difficult technologies, such as photovoltaics, may be closer to commercial realization. Many solar technologies already work, even though the best designs have not been found, and they are already facing the economic challenges that other long-range options have yet to confront. It is arguably time to reconsider solar priorities and ask whether the distribution of research resources among nuclear, fossil, and solar options reflects a rational policy.

ALLEN L. HAMMOND and
WILLIAM D. METZ

THE SUN IN A DRAWER

BY BRUCE ANDERSON

No shadows allowed

WIDESPREAD USE OF solar energy for heating and cooling buildings requires the solution of a number of problems other than those associated with the technical aspects of building and maintaining the systems. In fact, many of the technical problems have already been solved (see "Solar Energy," *Environment*, June 1973), but nontechnical difficulties persist. The basic difficulty is that extensive use of solar energy requires large-scale integration of new solar energy systems, ranging from specific solar components to properly designed buildings, into a complex of existing regulations which includes building mortgage criteria, property tax laws, building code standards, manufacturing restraints, construction methods, and labor requirements. The institutions responsible for the constraints are generally quite conservative and so far have not made major concessions to the concept of solar energy as an alternative power source. However, with the costs of conventional fuel rising, and with local and federal governmental agencies becoming involved with promotion of solar energy for heating and cooling, the stage appears to be set for very rapid development of this neglected source of power for basic building needs.

An indication of this potential is that the number of buildings using, or planning to use, solar power in the U.S. has risen in the past two years from a mere handful to several thousand. Rays from the sun are being used for energy in government buildings, schools, private homes, environmental institutions, and commercial establishments. Based on traditional economic criteria, the cost of solar energy now often competes with that of fossil fuels for the heating of buildings and water.

School buildings are particularly good structures for the application of solar energy. In January 1974, in an effort to speed promotion of the use of solar energy, and to show Congress some immediate results, the National Science Foundation (NSF) awarded four contracts for the construction of experimental solar heating systems in a high school, two junior high schools, and an elementary school. The program, called "Solar Energy School Heating Augmentation Experiments," is aimed at advancing the systems technology for using solar energy for space heating and hot water needs of buildings, and to provide important information on the degree to which such systems can be made economically justifiable and socially acceptable."[1]

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Refitting existing buildings with new solar equipment, as was done with the four NSF-funded school projects, is one of the most practical and important applications of solar heating. In many existing buildings, it is easier to reduce fuel consumption by adding solar heating systems than by adding insulation to the walls and roofs. Solar collectors can be attached to walls, installed on rooftops or placed in separate housings on the ground next to the buildings.

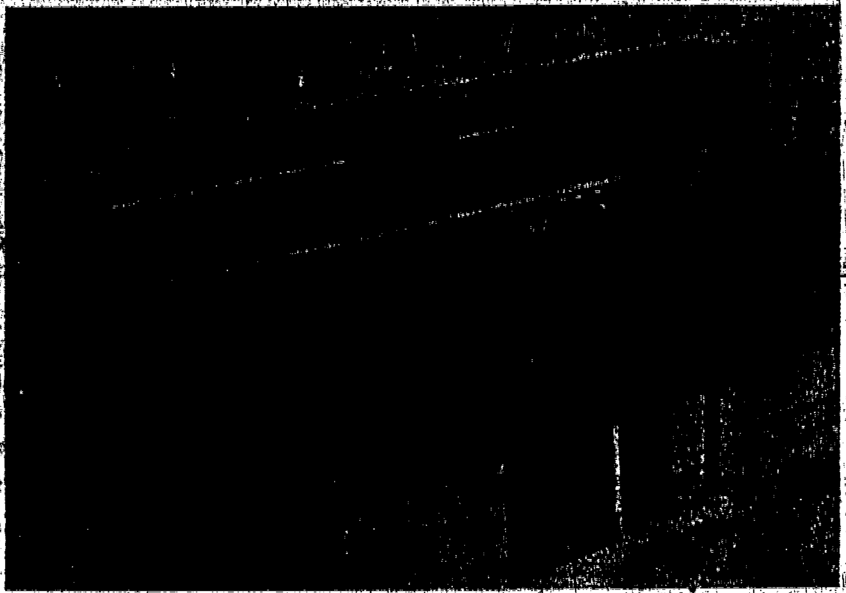
One of the oldest operating solar-powered buildings is a house located near the campus of the University of Florida in Gainesville. It was built in 1955 by members of the university's Mechanical Engineering Department for the purpose of measuring heat flow into and out of a home. In 1968, the house was refitted for conversion to solar heating. Power from the sun is now being used to heat the house, its water, and its swimming pool and to actuate its liquid-waste recycling system, which operates through water distillation. Solar energy also partially powers an electric conversion system for television, lights, radios, and small appliances in the house, and a solar-electric car. Solar air conditioning and refrigeration for the home are being installed.

Financing Difficulties

One difficulty in providing solar energy systems for private homes is that most people prefer to have complete solar heating or cooling systems rather than systems which supplement existing heating or cooling systems. But systems which provide 100 percent solar power are usually far too large and costly to be practical; provision of solar energy for 50 to 75 percent of heating needs is a more realistic goal for most buildings in most parts of the country.

Another problem facing the individual homeowner is that the initial cost of a solar system is usually higher than that of a conventional system. Home-financing plans are not usually designed to encourage such an investment even though lower heating bills over the lifetime of the system make it a sound buy. Financial institutions could ease the difficulty by taking into account the long-term benefits of solar energy resulting from lower operating and maintenance costs. At present, these institutions are instead inclined to concentrate on initial installation costs. It is hoped that the increasing costs of conventional fuels will cause changes in lending policies.

Many cost analyses have been done comparing the use of solar energy with the use of fossil fuels. George Löf of Colorado State University and Richard Tybout of Ohio State University have carried out some of the most extensive studies in this area.[2] Their results are promising (see Table 1). In their calculations, the original investment cost for solar energy system equipment was amortized over a twenty-year period at 6 percent interest. In the seven U.S. cities studied, projected solar heating costs were lower than the costs of electric heating and, in some cases, lower than gas heating costs. Although the study cited here uses reliable comparisons based on present fuel costs, fuel prices are likely to rise unpredictably, a factor which may alter the results of the study.



The Aluminum Assoc., Inc.

This home in El Cajon, California, uses aluminum solar collectors to provide heating.

Other cost-estimate studies, which take into account equipment costs only, have had varied results. Erich Farber, head of the solar energy group of the University of Florida's Mechanical Engineering Department and one of the world's leading authorities on solar energy, estimates that equipment for his system for total solar heating and cooling of a house in Florida would cost about $5,000 more than conventional equipment. On the other hand, another expert in the field, Harold

TABLE 1
COSTS OF SPACE HEATING (1970 PRICES)
(DOLLARS PER MILLION BTU USEFUL DELIVERY)

	Estimated Solar Heating Cost			Fuel Heating (fuel cost only)	
Location	Collector ($2/ft.²)	Collector ($4/ft.²)	Electric Heating	Gas	Oil
Santa Maria	1.10	1.59	4.28*	1.52	1.91
Albuquerque	1.60	2.32	4.63	0.95	2.44
Phoenix	2.05	3.09	5.07	0.85	1.89
Omaha	2.45	2.98	3.25†	1.12	1.56
Boston	2.50	3.02	5.25	1.85	2.06
Charleston	2.55	3.56	4.22	1.03	1.83
Seattle-Tacoma	2.60	3.82	2.29**†	1.96	2.36
Miami	4.05	4.64	4.87	3.01	2.04

*Electric power costs are for Santa Barbara. Electric power data for Santa Maria were not available.
**Electric power costs are for Seattle.
†Publicly owned utility.

Hay, estimates that new equipment for the use of his flat water-bed-type collector on his totally solar-heated and -cooled house in Atascadero, California, would cost no more than the furnace and air-conditioning system it replaces.

Traditionally, housing developers have been interested in keeping costs as low as possible, a goal frequently incompatible with comprehensive solar energy systems. However, developers, too, may have difficulty in obtaining gas and oil for new houses in the future; it would be to their advantage to consider alternative sources of energy.

Those elderly people who can afford the high initial investment of buying a house, but would like to be assured that their fixed retirement income will not be eaten up by increasing fuel bills, may find that solar energy can provide a solution for this problem. Amortization of the cost of solar energy equipment along with the cost of the home could assure relatively stable future heating and cooling expenses.

The Connecticut state government has taken the initiative in providing such housing for the elderly. In December 1973, Governor Thomas J. Meskill announced a program that would allow the state to spend $400,000, with the assistance of additional federal funds, on an experimental project for solar-heated housing for the elderly. Construction of 40 units is planned; 20 units will be equipped with solar energy devices to provide supplemental heat, and 20 identical units, which will serve as controls, will utilize only conventional heating fuels. In this way, the costs of the two systems can be compared. In announcing the program, Meskill noted that average annual electric heating bills for elderly people were $192 in 1967, but had risen to $380 by 1973. In late 1974, the NSF announced that it would fund the project's initial planning and design studies.

Another financial consideration is that the extra employment stimulated by the development of the use of solar energy can be a boon to local economies. For example, most of the gas and oil used for heating in New England is shipped there from other regions of the country or is imported. Annual cash outflow for this purpose amounts to billions of dollars and is increasing every year. Materials such as glass for solar panels are likely to be manufactured in the U.S.; these components are inexpensive to produce but costly to transport, a factor which will make local assembly practical, thus diverting money from foreign markets to local economies. Furthermore, installation of the manufactured equipment would utilize local labor.

Tax Incentives

Since real estate taxes are based on property values, higher initial property costs result in higher taxes. Lowering these taxes to encourage the use of solar energy in homes and other buildings is a desirable goal, but assessment of property taxes is often locally controlled, and change in this area is difficult.

Indiana has taken the lead in modifying this situation by offering a real estate tax incentive for using solar energy components in both new and existing buildings. Property values are to be determined by subtracting the value of the solar heating system from the total valuation, or by subtracting $2,000, depending on which method gives the greater remaining taxable value. Other states, including Arizona, California, and New York, are now considering this approach.

Other incentives for solar energy systems, now under consideration by the federal government, are low-interest, government-subsidized loans. These loans could be made both to building owners and to manufacturers. The Department of Housing and Urban Development is developing interim solar energy design criteria for homes financed by the Federal Housing Administration and may insure home-improvement loans for the installation of solar energy in existing homes. Income tax write-offs for solar-powered systems are also being considered in Congress. Such deductions would be based on a percentage of the installation cost of the system or of the energy savings made possible by the system.

Design and Manufacture

One of the main difficulties in the design, manufacture, and marketing of solar systems is the necessary combination of good performance, long-lasting materials, and economy of operation. The designer must have a sophisticated understanding of the workings of solar energy in order to avoid the pitfalls which have been discovered in the past. In most instances, the system's design must fit into the design of an existing building. The necessary research and testing are expensive and arduous, and many architectural and engineering firms hesitate to invest extra time and money in the design of solar systems and buildings. Those firms which do take on such projects often find it practical to delay the selection of components until the last possible moment, since new technology is constantly being developed, and increasing mass production of components is bringing costs down.

Manufacturers are moving more quickly to close the present gap between the availability of finished solar components and the demand for them. There are at least 50 manufacturers seriously involved in these developments and several hundred others who are carefully noting the increasing demand for solar energy, keying their investments in solar component production to the market. The existing market, however, is fragmented, and new markets need to be developed. Manufacturers are understandably reluctant to tool up assembly lines before an adequate popular demand develops, but this kind of development is not likely to take place until high-quality solar collectors are made available for sale at reasonable prices.

Agencies with the funding power necessary to promote solar energy design, such as the NSF and the Energy Research and Development Administration (ERDA), are spending little to train the needed contractors and technicians. This reluctance adds to the shortages found by interested designers and manufacturers in their efforts to develop a solar energy industry.

Organizations are now being formed to aid manufacturers interested in solar energy. The Solar Energy Industries Association, comprised primarily of manufacturers, was organized in 1973

Owens-Illinois, Inc.

Owens-Illinois hopes to make their SUNPAK™ collector directly competitive with fossil fuels.

to "stimulate prompt, orderly, widespread, and open growth of economic utilization of solar energy." It was formed in conjunction with the Washington, D.C.-based Solar Energy Research and Information Center, a "specialty service organization devoted exclusively to assisting persons, companies, governments, associations, and other organizations" in promoting the use of solar energy. This organization publishes two bi-weekly newsletters, the "Solar Energy Washington Letter" and the "Solar Energy Industry Report." Other services offered are "legislative and regulatory liaison, special reports, and consulting."

Do-It-Yourself

Although a large number of solar collectors may soon be available from manufacturers, custom design and on-site construction of solar collectors will probably remain viable alternatives to the use of finished solar designs. For example, Arthur Cotton Moore and Associates in Washington, D.C., has designed a science building for Madeira School in McLean, Virginia, which has a total area of 8,000 square feet and uses a 4,000-square-foot solar collector. The preliminary plan calls for solar heat only. Like most solar energy projects, the plan has two parts: The first task is to design the system with available off-the-shelf components in mind; the second is to contact manufacturers who have equipment which can be suitably adapted to the design.

However, one of the primary difficulties with on-site construction is that a great number of designs have been patented. Designing new systems is expensive, and, at present, there are only a few designs for sale to those who wish to build their own collectors.[3] Nevertheless, on-site construction should be considered because of the present difficulty in obtaining commercial solar collectors.

Construction Barriers

There are several other potential problems centered in the housing construction industry and in the laws which regulate it. The industry has a record of excruciatingly slow adaptation to change, particularly when change means higher construction costs. There are thousands of builders; thus, the industry is highly fragmented, with 90 percent of all construction work done by companies which produce fewer than 100 units each per year. Even the largest building concerns each produce less than 0.5 percent of all housing units. The profit margin in this industry is already small, and innovation in a first-cost-oriented industry such as solar heating and cooling is a risk which few builders will take. Fortunately, the use of solar energy is being tried by some contractors and developers to evoke interest in new housing developments, an effort which may bring increased sales during recessionary periods.

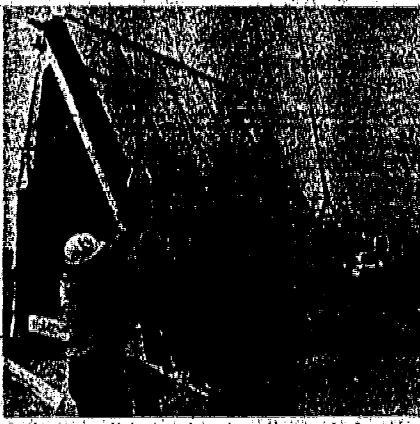
Building codes are designed both for safety and business purposes. There are presently about 30,000 different building code jurisdictions in the U.S., many of which have mutually incompatible requirements. Fire codes are the ones most likely to affect the implementation of solar energy; these codes are relevant to three of the components in solar energy systems. One is the heat storage system. Paraffin is a good heat storage material for possible use in these systems. As it melts, paraffin stores large amounts of heat, and it releases that heat as it solidifies. However, because of paraffin's flammability, some fire codes may not allow the substance to be used inside buildings.

A second component subject to fire code regulations is the solar collector cover plate. Unbreakable plastics and fiberglass are alternatives to glass for use in cover plates; such products are generally less smoke- and fire-resistant than glass, but since the cover plates are installed on the outsides of buildings, the problem would only present itself in the case of external fires.

The third component to consider in regard to fire codes is the material used for insulation on the back sides of solar collectors. Insulation materials include fiber glass, polystyrene, and polyurethane. All insulation materials are generally in relatively close contact with the solar absorber plate, which can reach temperatures above 350 degrees F., and many materials can melt or smoke at these high temperatures. Insulation should thus be separated from the absorber plate by at least a three-quarter-inch air space and should be faced with reflective foil.

Health codes must also be considered. These codes can apply when ethylene glycol (mixed with water to prevent freezing) is used as a heat transfer medium. This chemical can contaminate drinking water, and precautions must be taken to insure that leaks in the system are avoided.

Still other building codes may limit the use of solar energy. A height restriction for buildings in one area along the shoreline in Long Island Sound in Connecticut has resulted in an unfamiliar but pleasant building design for a solar home. Thus three-bedroom, year-round residence, completed in 1974, was designed to obtain 60 percent of its heating energy requirements from a



Collector unit to be placed on the roof of the Gump Glass Company building in Denver, Colorado.

modular flat-plate collector system designed by Everett Barber, Jr., and sold by Sunworks, Incorporated. The system was estimated to cost $3,500 more than a conventional heating system, but it has cut fuel costs from $600 to $300 per year. Zoning height limitations required that the roof be low; therefore, the three south-facing collectors are arrayed in a sawtooth fashion, an arrangement which also provides clerestory lighting for the interior of the home. The total area of the solar panels is about 20 percent of the home's 1,900 square feet of living area. Other energy-saving features in addition to the solar heating system include the sizing and placement of windows to provide for maximum natural daylight and ventilation. The overhangs above the large window areas reduce the sun's heat in the summer, but are built at an angle which allows the sun's rays to penetrate the house during the winter. Solar air conditioning will be installed in the house in the future.

Sun Rights

Architectural agreements allowing for unobstructed exposure to the sun's rays may be necessary as more buildings begin to rely on solar radiation as their source of energy. Legislative steps may have to be taken to guarantee that neighboring construction and vege-

This new solar home at the Ohio State Fairgrounds in Columbus is the first in Ohio that uses hot water, cooling and heating provided by solar energy.

tation does not reduce the amount of solar energy which strikes a particular building. California is presently leading the country in attempting to provide "sun rights" through legislative action. Until such laws are enacted, however, the use of solar energy may be subject to interference from new buildings or from shade trees.

An example of the importance of sun rights is shown in the design development of SolarCon Center, a $48-million project comprised of a 28-story office condominium and a 22-story professional building. It is being designed by the Messineo Financial Corporation of Pasadena, California. At first, solar collectors were to be installed on the south wall of the tallest building, but the unresolved threat of possible shadowing by adjacent construction led to a rooftop collector design.

The possibility of vandalism of the transparent cover plates of solar collectors has been of great concern to designers and potential buyers of solar buildings. However, over the 30-year history of the use of solar energy in the U.S., which saw the completion of approximately 25 solar energy projects prior to 1965, vandalism has not been a problem. Other all-glass buildings have likewise experienced relatively minor difficulties with vandalism.

Another inherent drawback which has concerned designers is that the sun's reflection from large expanses of glass-covered collectors may affect pedestrians, drivers, and people in nearby buildings. However, except in rare cases, the expanse of solar collectors will not nearly approach the large expanses of some all-glass buildings. Glare from such buildings has not usually been found dangerous; in most cases, the effect is not as severe as that experienced when driving directly into the sunrise or sunset.

The Future

In looking ahead, it appears that the use of solar energy for heating and cooling will probably have quickest acceptance where climates are sunny and temperate, permitting the application of solar energy during a large part of the year, and when conventional fuel costs are as high or higher than the cost of using solar energy. Solar heating can also be used effectively in areas where the winters are long and cold, but sunny, as these areas have a great demand for heating fuel and have adequate sunlight for optimal use of solar energy.

The coordination of supplemental services by gas and electric utility companies will be increasingly important as solar buildings increase in number. For most solar designs, the peak demand on the utilities will occur after several sunless days. This demand would be intensified if there were a corresponding peak demand on the utilities by other customers in the service territory. Thus, not only would the homeowner be required to install a full-sized nonsolar back-up system, but the utility companies would have to have extra generating capactiy to meet occasional peaks. In the past six to twelve months, utility companies across the country, along with several federal agencies, have shown an increased inclination to search for solutions to this future dilemma. The NSF, ERDA, the Federal Energy Administration, and the Electric Power Research Institute are all funding research studies related to the problem.

Another important consideration is that the use of energy for space heating, hot water, refrigeration, and air conditioning accounted for 11.5 percent of total energy consumption in the U.S. in 1968. What is more impressive, these applications consumed 28 percent of the energy used for industrial purposes and 76 percent of the total energy used by all commercial enterprises.

Wide press coverage and greatly increased governmental legislation and funding indicate that, as interest continues to develop, millions of people will be participating in the use of solar energy. It is possible that future use will exceed even the most optimistic predictions of the speed with which solar energy will reduce the need for consumption of other forms of energy.

PPG Industries

The title of this article as originally submitted was "Here Comes the Sun." The Publisher and Editors of Environment are responsible for the published titles and subtitles, selection of photographs and lead-in excerpts, photo captions, and preparation of most graphs and illustrations which appear in Environment articles.

NOTES

1. National Science Foundation news release, Feb. 1974.
2. Tybout, Richard A., and George O. Löf, "Solar House Heating," Nat. Resources Jour., 10(2):268-326, Apr. 1970; Löf, George O. G., and R. A. Tybout, "Cost of House Heating with Solar Energy," Solar Energy, 14:253-277, 1973; Löf, George O. G., and R. A. Tybout, "The Design and Construction of Optimized Systems for Residential Heating and Cooling by Solar Energy," Solar Energy, 16:9-18, Aug. 1974.
3. For two such sources, contact Edmund Scientific Co., Barrington, N.J., and Zomeworks Corporation, Albuquerque, N.M.

TINKERING WITH SUNSHINE

THE PROSPECTS FOR SOLAR ENERGY

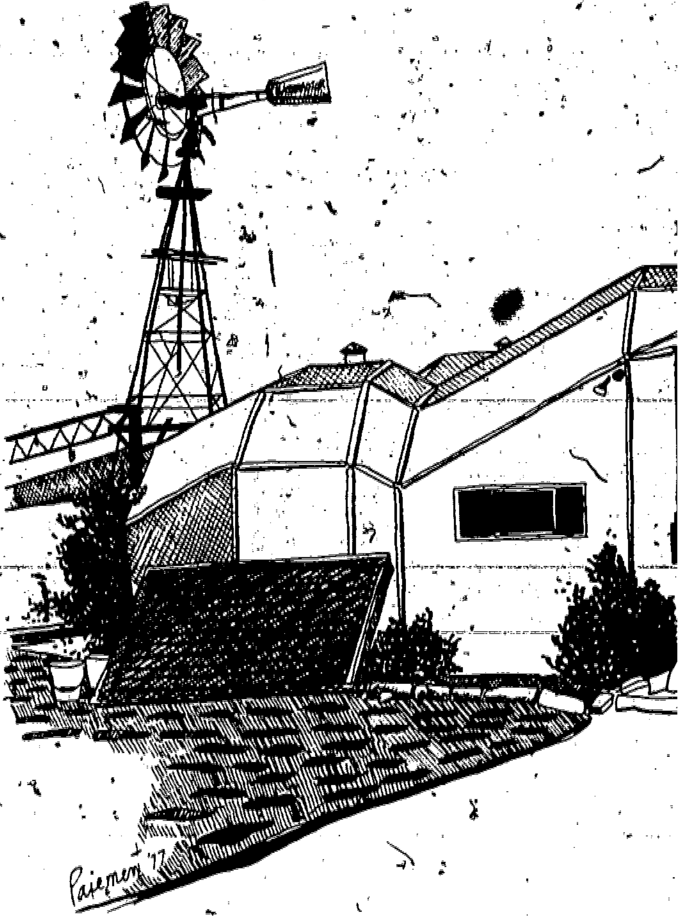
by Tracy Kidder

Oil grows scarcer and more expensive . . . nuclear power becomes increasingly controversial. But consider the sun. The world basks in an inexhaustible source of power, although the technology for using it hardly exists. At the moment solar energy is a field for visionary inventors and entrepreneurs hoping to build the Model T that will give birth to a new industry.

In October 1976, on the eve of the natural gas shortages, a twenty-nine-year-old physicist named Amory Lovins published in *Foreign Affairs* a treatise called "Energy Strategy: The Road Not Taken?" Since then, the Lovins article has become something of a focal point for the debate over national energy plans.

We can travel into the future on one of two paths, Lovins writes. The one generally favored by U.S. policy has the nation increasing energy production in all possible ways, but mainly through exploitation of fossil fuels and old-fashioned nuclear fission. Later, in "the era beyond oil and gas," come large-scale, "arcane" energy systems: breeder reactors, nuclear fusion devices yet to be fully imagined, huge space stations gathering electricity from the sun and beaming the juice to earth in the form of microwaves. Lovins calls this "the hard path." In Lovins's view, it is a road with dire social consequences: energy wars, repression at home, environmental degradation, and several kinds of catastrophes associated with uranium.

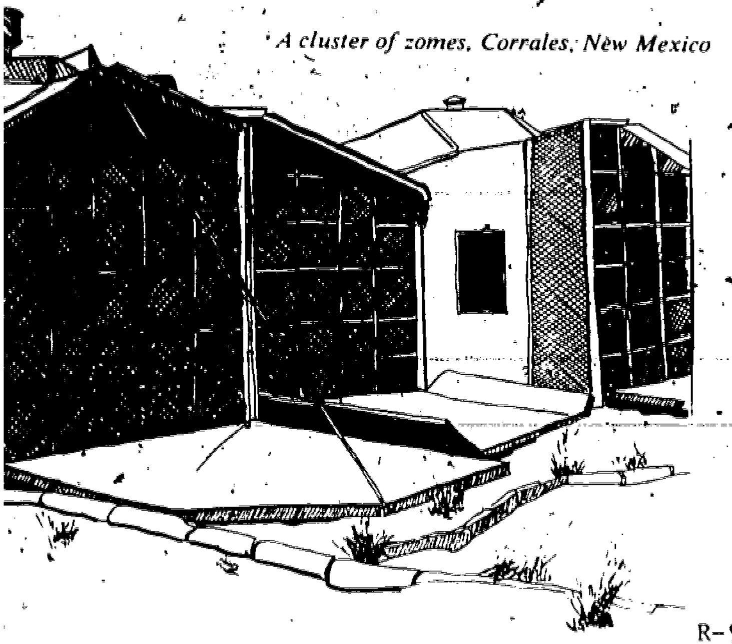
We can follow the other path, "the soft path," Lovins continues, by engaging in a new and "elegant frugality." The country maintains its standard of living, but Detroit and Con Edison and the average homeowner learn to conserve truly vast amounts of fossil fuels. In this way, time is bought. We use it to turn, not to new nuclear reactors, but to "benign," renewable sources of power and heat, and we end up, in about fifty years, living off our "energy income": chiefly sunshine and solar products like the winds. The technologies employed then are diverse, easy to understand, safe, relatively clean, and invulnerable to nation-crippling accidents and sabotage because, for the most part, they are deployed at the community level. As a consequence, democracy grows stronger.



Our energy suppliers are no longer "alien and remote." Local autonomy prevails. Nuclear reactors are now antiques and at last there is a chance for peace among nations. Lovins argues that we must choose one path soon, because the country lacks the material and spiritual resources to follow both.

Lovins's scheme for a "soft" energy future rests largely on an optimistic view of solar technologies. It's a faith that many share. Surely sunshine is the most enticing of energy sources. It can be "mined" in ways that appear to be harmless, and there's more than enough to go around. Contemplation of the sun's power leads even respectable scientists to grandiose hypotheses; one physicist has calculated that if we could convert to mechanical power all of the solar radiation that strikes the United States in just a day, we could lift the entire Republic—and the 1000-meter-thick crust it sits on—about three and a half feet into the air. For those who feel that mankind must find a way around plutonium, who wince at news of each new oil spill, the sun is today's messiah. I pick up small-town newspapers and college alumni bulletins and again and again I read of people who have discovered the guiltless joys of using solar energy in the home. It's the self-reliant way. It's the way to harmonize with Mother Earth, while keeping the Arabs out of Fort Knox. But how much energy can we get from the "soft" solar technologies, from such things as windmills, solar ponds, solar space and hot-water heating systems, from rooftop arrays of those marvelous photocells that make electricity from sunshine? And how soon can we get it? What is the real market potential of these technologies?

The Office of Technology Assessment and the Stanford Research Institute, the Energy Research and Development Administration (ERDA), Mitre Corporation, Westinghouse, GE, Thompson Ramo Wooldridge, Inc. (TRW), and the National Science Foundation are some of the organizations that have looked into the future of solar energy. The House and the Senate have held hearings; the collected volumes of testimony on this subject generated by just one Senate committee have a total weight of about twenty-five pounds. A forty-one-year-old solar architect named Gordon Tully holds that solar technologies will have come of age when the thermal energy produced by all the solar collecting devices in the United States is equivalent to the thermal energy that would be produced by burning all the solar studies. Out of this forest of paper come many conflicting predictions.



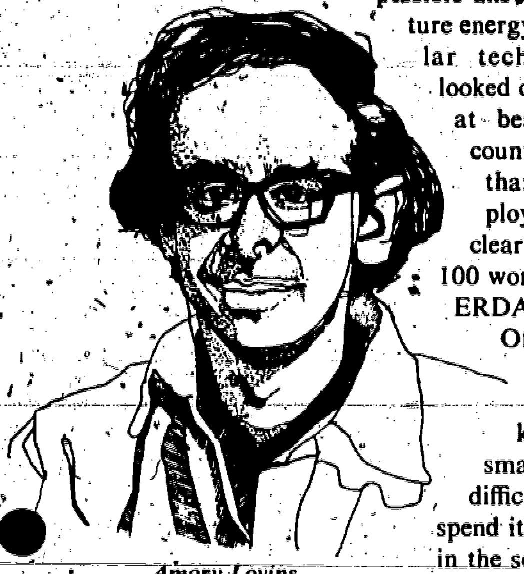
A cluster of zomes, Corrales, New Mexico

It isn't surprising to find that there is no consensus on what can be done with the sun, because there has been little hard research to go with the studies. In 1952, the Paley Commission prepared a report for President Truman called "Resources for Freedom." It was a prescient document. It warned of future oil shortages and of a growing dependence on the Middle East, and it recommended "aggressive research" into both the "peaceful atom" and solar technologies. But successive administrations and Congresses took only half that advice. From 1953 to 1973 the U.S. government spent some $5 *billion* on research and development in nuclear energy, but less than a million on solar technologies.

Government spending on solar research did not begin until 1974, after the Arab oil embargo and in the midst of growing protests against nuclear power. Since then, government financing has come on strong, thanks to a generally enthusiastic Congress and, more recently, to the Carter Administration. In fiscal year 1978 the government will spend a record $368 million on solar research, development, and demonstration, and the subsidy will be still larger if, as now seems certain, Congress goes along with the President's plan to allow tax credits for people investing in solar-heating equipment. Meanwhile, however, about $3 billion will go to R&D in nuclear technologies, and the lion's share of that will be spent on the breeder reactor and on fusion, which face futures at least as uncertain as those of most solar technologies.

The usual explanation for this apparent double standard is that solar technologies simply don't need as much money as nuclear ones. Energy bureaucrats also say that the infant solar industry isn't large enough to absorb more money than it's getting. But many disagree. Henry Kelly, a thirty-two-year-old staffer in Congress's Office of Technology Assessment, has helped to draw up a study of possible approaches to solar energy. The list is huge. Kelly concludes, "Anybody who says more money can't be spent on solar technologies is just wrong."

In general, the strongest barriers to larger, useful investments in solar energy appear to lie within the government itself. Soon to be assimilated into the new Department of Energy, ERDA has been a true child of the old Atomic Energy Commission, which it replaced several years ago. The prevalent attitude within ERDA has been that nuclear power is the only possible answer to the country's future energy needs. Meanwhile, solar technologies have been looked on as small contributors at best, and at worst, as countercultural toys. More than 2000 of ERDA's employees are involved in nuclear programs, and a mere 100 work in the solar division. ERDA's hierarchy and the Office of Management and Budget, which control staffing, have kept the solar crew small, and this has made it difficult for the division to spend its money wisely. People in the solar division talk about working twenty-hour days. They admit that they aren't able to monitor properly even their existing programs.



Amory Lovins

Space and hot-water heating are the most readily practicable of all the solar technologies. Government projects, along with the Arabs and the brutal winter of 1977, have created a boom in the craft. In the early 1970s there were only about 100 solar-heated houses in America. Now there are several thousand and many more on the way, and it is certain that there are even more people working on solar heating than there are solar-heated houses. Professors at more than a dozen universities and something like 550 companies (some large and many small) have entered the competition. It seems the public has been aroused; the government-sponsored Solar Heating and Cooling Information Center has been receiving about 3000 phone calls a week from interested citizens.

About a quarter of all the energy used in America goes to heating buildings. So solar heating could be significant. But how significant? Is Lovins right when he says that this technology is "now available and economical"? With those questions in mind, I went out in the spring and summer of 1977, into a few regions of solar-heating land, to see what part of the future was there.

Two views from Olympus

An important moment in the history of modern solar-heating technology occurred in 1939, when a team of MIT engineers, led by a young assistant professor named Hoyt Hottel, built a small house outside of Boston and fitted it out with a rooftop "flat-plate" collector. Copper pipes were mounted on a copper surface and the whole thing was covered with three layers of glass. Water was pumped through the pipes on the roof, heated there by the sun, then sent to the basement into a large steel storage tank. The heat was transferred to air and finally circulated through the house by a blower system, as the need arose. This was the prototype for most of the "active" systems on the market and in houses today—systems, that is, in which air or water, moved by mechanical means, carries the heat around. (In a "passive" system, parts of the house itself collect the heat, which is distributed with little or no help from machines.)

The first MIT house was nothing more than a laboratory: Hottel used it to establish the basic engineering principles behind solar collector performance and was so meticulous that his calculations served to correct the Weather Bureau. That first house worked; Hottel was able to use summer sun to heat the building in the winter. But the storage system was huge, "an economic monstrosity," according to Hottel. So his team built another house, this time using a south-facing wall of water, a more or less passive system. But they weren't able to insulate the window well enough after dark to keep heat loss at a satisfactory level. So they went back to active systems and built two more houses, and in 1962, after twenty years of experiments, Hottel and his team "shelved" space heating. "We had gotten the data to know it was uneconomical at the time."

It is May 1977, somewhere near the end of the era of cheap oil and gas, and Hoyt Hottel—MIT professor emeritus, seventy-four and white-haired—sits in his office before a large plate-glass window, looking out on a corner of MIT's labyrinthine campus. He is justifiably proud of his work, but grows dour when he turns to the object of all those meticulous experiments. He says that over the years he has watched the costs of solar space heating continually hover above the rising costs of conventional heating, and although he allows that the solar approach may now be almost competitive with expensive, inefficient, electrical-resistance heating, he believes it is still much more costly than heating with oil or gas.

A consultant from Arthur D. Little would tell me

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*Tracy Kidder is a free-lance journalist who often writes about environmental topics.

later, "Hottel hasn't heard of the oil embargo." A prominent inventor of passive systems would say, "Hottel's a man who bought a ticket on a horse and threw it away before the race was over. Now he can't bear to think that his horse might come in." Hottel, for his part, has said that solar-heating enthusiasts base their case on emotion, not on natural law. He describes their reasoning as follows: "Solar energy has to be a good thing. . . . Out of the window with embarrassing negatives; I've made up my mind." Hottel doesn't say that solar heating won't become important sometime in the future, but he says that a future which includes it isn't one to anticipate with relish. "I think you have to say that when solar energy does become important, that will be a measure of the fact that we are not living as affluently as we do today," he told me. "Because by present standards, it is by no means the cheapest way to get energy."

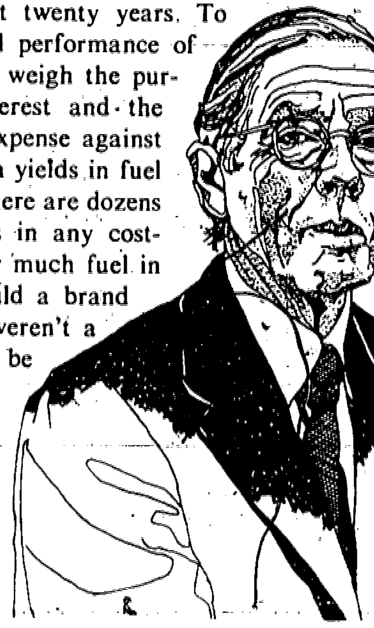
There is no disputing Hottel's central point. No source of energy, whether it's solar or nuclear or geothermal, will be as cheap and easy to grasp as the stuff we've been using these past 100 years. But it's because of this fact that solar heating now looks more practical than ever before. To some, in fact, this is the beginning of its exciting, even its romantic, age.

On the other side of Cambridge from MIT, near the now-defunct Harvard cyclotron, there is a little office crammed with books and articles on solar heating. In the filing cabinets lie hundreds of letters from well-known and anonymous solar inventors. Everything is in order. The size of the office and the complexity of the subject make order mandatory. William Shurcliff, a sixty-eight-year-old honorary Harvard research fellow, studies other people's inventions in here. He is the preeminent cataloguer of solar space-heating brainstorms, the author of *Solar Heated Homes: A Brief Survey*, which he has taken through thirteen editions in the last five and a half years. Shurcliff knows what is out there, if anyone does. Visiting him one day, I remarked that a friend who was building a solar-heated house had hit upon the idea of improving his collector's performance by dyeing the water inside it black. A novel idea, I had thought. Shurcliff said, "Hmmm. Black water." From the shelf over his desk he pulled down a thick looseleaf notebook, looked up "Black Water" in the index—"I think books without indexes should be banned, don't you?"—and proceeded to read off a list of about five companies and "lone wolf" inventors who'd tried it. And then there were several people with hot-air systems who had tried black dust. "So you see there's been quite a lot on that."

Shurcliff is tall and thin and he speaks in the accent one often hears on the seacoast north of Boston. He describes himself as "a tired old optics man." "The electromagnetic spectrum is one of the grandest things in the universe," he told me. "I've spent most of my life working in parts of it, so it was very easy for me to get into this field, and I did it eagerly." For about thirteen years he worked in optics and radiation at Polaroid. Then he came to Harvard and ran radiation security for the atom-smasher, and when his duties ended there some five and a half years ago, he took up solar heating, thinking at first that he would spend his time inventing. He still keeps his hand in, but he found that in general other people's ideas were more interesting than his own, and so he became a cataloguer, the first and, until recently, the only cataloguer of space-heating ideas.

At least once before, Shurcliff has devoted himself to a cause. He is generally credited with a large role in the successful campaign against the SST; mainly, he wrote courtly, threatening letters. These days he could be described as a solar advocate. "This world damn well needs solar heating," he says.

Shurcliff does believe that the solar-heating art can be practical, but he is aware of the problems. "Hurdles," Shurcliff calls them, disdaining the ordinary word. First among them stand the questions of cost, durability, and performance. In an industry so new, durability is hard to predict, but it is assumed that a good system will last twenty years. To measure the cost and performance of the system, one must weigh the purchase price with interest and the yearly maintenance expense against the savings the system yields in fuel or electric bills. But there are dozens of unknown variables in any cost-benefit equation. How much fuel in any given winter would a brand new house use if it weren't a solar house? What will be the rate of inflation, where will interest rates stand, what will maintenance cost, and, the crucial question, what will be the prices for gas, oil, and electricity? Will there be enough of those commodities to go around, come January 1985? Several studies have attempted to deal with the economic question and several have concluded that solar heating is practical today. But those conclusions are based on a plethora of averages, and there really is no such thing as an


William Shurcliff

average solar-heating system, an average house; or, in many places, an average winter. Shurcliff seems more reliable. He has studied particular systems. He thinks that at least 80, and maybe 97 percent of them aren't a bargain, not as they are measured beside today's gas and oil prices.

Hard enough, then, to make a solar-heating system pay when it's installed on a new house designed with the sun in mind. "How much more difficult it is," exclaims Shurcliff, "to 'retrofit' solar heating to an existing, badly insulated, imperfectly oriented house in a region crowded with tall trees or tall neighboring buildings!" Perhaps householders will be persuaded to undertake retrofits as home improvements or as security against some dark, cold, fuel-less winter. Maybe, as Shurcliff suggests, some will decide that it's fun, "like owning a yacht." But economics will weigh heavy, and retrofit will always be an expensive proposition, like any remodeling job.

Although sunshine is free, the nation would have to pay a price for widespread solar heating. Putting the systems in place would require large amounts of labor and natural resources such as copper. A great deal of energy would be expended; it takes about five years for a well-designed system to gather as much useful energy as it took to build it. A host of small problems must be dealt with, too. For example, experts agree that the most economical systems provide only part—somewhere between 30 and 60 percent—of the heating needs for an average house. So a back-up system is required, and an electrical one is usually the cheapest to install. But thousands of solar houses in a given area, using electricity only on cold, cloudy days, would force the local utility to invest in equipment that would be used just a few times a year. The result would be special high electric rates for solar-heated homes. A possible solution, now being investigated, is to have solar-home owners turn on the power only during the utility's off-peak hours, and use this electricity to heat up their storage systems.

Shurcliff seems a careful man. He approaches the future cautiously, by asking questions. But five and a half years of studying the designs that now fill his books and filing cabinets seem to have left him in a state of controlled excitement. "We deal, indeed, with a ferment," he writes. In his little office, it is 1905 and a new industry is stirring. There are hundreds, maybe thousands, of people banging metal in their back yards, trying to build automobiles. Just which of these curious contraptions is the ill-fated Hupmobile and which the Model T is hard to say. But Shurcliff has seen a great many small ideas, and also some complete systems—maybe 3 or 4 percent of the total—that show definite promise. They look cheap and they work, though some seem "crude" today. No single one seems perfect for all climates, but that is no real problem.

"I'm willing to go out on a limb," Shurcliff told me. "I think that there will be dozens of winning schemes."

Rhombic dodecahedra and other works of genius

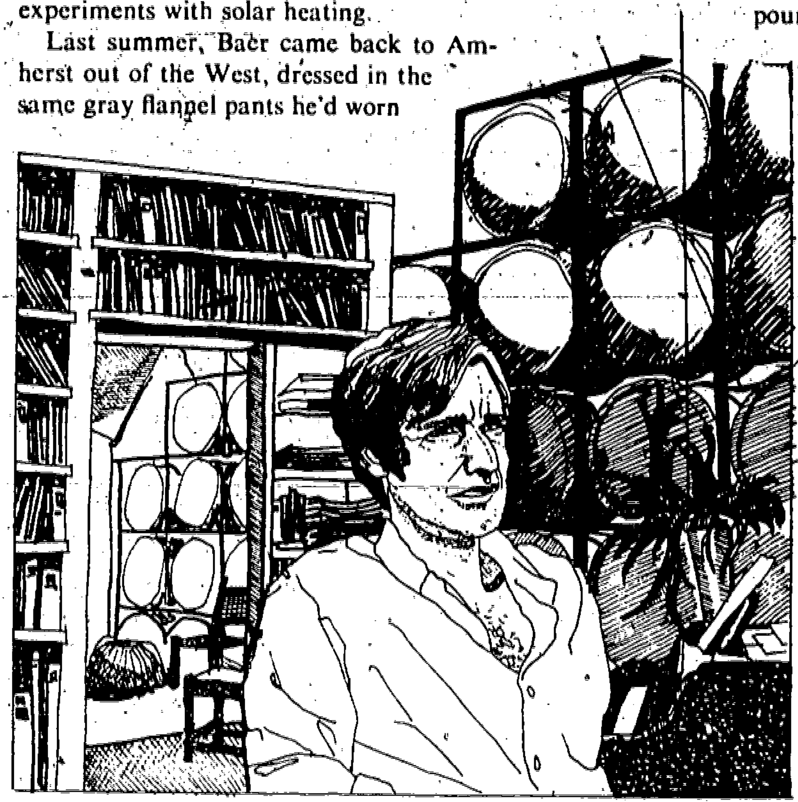
In Corrales, New Mexico, near Albuquerque, there stands an amazing private residence, not a house in any ordinary sense, but a series of metal structures connected to each other, silvery and strange, standing in rugged, treeless terrain. Steve Baer, who created this place, who built it and lives in it, describes the structure as "ten exploded rhombic dodecahedra stretched and fused to form the different-sized rooms." He also describes his home as "a cluster of zomes."

A closer look reveals that arrays of used, fifty-five-gallon oil drums, filled with water and laid horizontally behind single sheets of glass, make up the southern walls. These are the prototypes of the now famous (in solar heating circles) "drum wall." The walls are equipped with large insulating panels which Baer raises and lowers like drawbridges with a simple rope and pulley device. He drops the panels on winter days to let the sun heat the water drums, and raises them at night to keep the heat in. The walls were cheap to build—about $5 a square foot, which is roughly half the cost of conventional rooftop collectors. They do about 75 percent of the heating in the zomes, allowing, that is, for indoor temperatures that vary from about 55 to about 80 degrees. Baer, who has always been interested in weather, thinks it's fun to live in a house that reflects what's going on outside. Some people do not like the temperature fluctuations or the walls, of course. "He'll sell his stuff by word of mouth," one conventionally minded solar engineer told me. "Word of mouth is the only way to persuade people to put fifty-five-gallon drums in their living rooms." But Baer and his company, Zomeworks, have already been employed on some 200 solar-heating projects, and orders for Zomeworks devices come from all over the country these days.

Out of Zomeworks comes the Beadwall—plastic beads are blown into the space within a double-glazed window on cold winter nights and sucked out with a small vacuum-cleaner motor when the sun rises. Baer and his colleagues invented the Skylid, an insulated shutter especially good for skylights: the shutter opens and closes by itself, at the direction of two small thermostats. Baer has been a pioneer in Convective Air Loop Rock Storage (a way of using natural convection rather than the usual mechanical blower to move heated air in and out of a storage system made up of stones), and he thought up something he calls the Double Bubble Wheel Driving Engine. Run by the effect of heat on bubbles in water, it can be solar-powered. There is no end to his inventions. He says he wants to be like Charlie Parker and never play the same tune twice.

Born and raised in California, Baer went to Amherst College and left before graduation. After a stint in the Army, he studied math and physics in Zurich, then came back to the United States. It was the 1960s. Baer wandered around a while, stopping in at some of the communes then flourishing. There he began his experiments with solar heating.

Last summer, Baer came back to Amherst out of the West, dressed in the same gray flannel pants he'd worn the first time he came to college, twenty years before. He is thirty-eight, slim, has sandy hair conventionally cut, piercing blue eyes, and was tanned when I met him. Someone told him that he looked like a representative from NASA, he was so clean-cut. I overheard someone else say that he looked like Gary Cooper.



Steve Baer and his drum wall

The occasion for Baer's return was the University of Massachusetts's "Toward Tomorrow Fair," a grand celebration for a dubious future, featuring music from Pete Seeger and speeches from Barry Commoner, Buckminster Fuller, Julian Bond, and Ralph Nader. Out on the fairgrounds, there were hundreds of displays. There were fine-looking wood stoves and pretty windmills, a wind-driven car, many kinds of waterless toilets, chain-saw sculpture, a teepee inside which foot massages were being administered, and lots of booths which bore such names as "Planetary Citizens" and "New England Institute of Appropriate Technology." Some very satisfactory-looking, flat-plate collectors were on display as well.

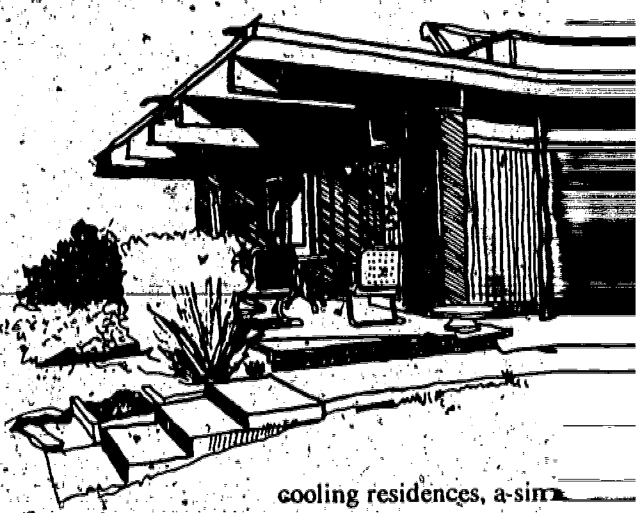
Up from the fairgrounds, outside a U.Mass lecture hall, a huge sign, painted in a shaky hand by a rather hysterical woman, a solar energy buff whom I met later on, said, "WELCOME STEVE BAER!" The line for his lecture was several hundred yards long and many didn't get in. They missed something.

The first half of Baer's speech was a stew compounded of ideas familiar to disciples of Abbie Hoffman and to students of the nineteenth-century laissez-faire economists. It was a eulogy for the hippies and the communes of the sixties. It was a lament for something he called "the free economy." It was an angry diatribe against government involvement in solar heating. At one point Baer began to chastise Exxon for the ads it has been running in magazines and newspapers, cautionary ads about solar energy. The audience showed it was with him. But then Baer seemed to draw back and eye the crowd. Suddenly he was saying that the oil company executives were "just people." "If we were in their place we'd do the same thing they're doing." And a little later on: "Alternate energy! That's a bunch of junk. It doesn't have anything to do with good design." And to what was now a mainly silent house, though I heard some nervous-sounding laughter around me, Baer announced, laughing heartily himself: "I didn't believe in the alternate-energy future until I saw how dull it was gonna be and how stupid the slogans were gonna be and how much I wasn't gonna like it. Then I knew it would come."

Afterward, over drinks at the Student Union, I got Baer onto the subject of Hoyt Hottel. Baer said that after he had built the drum wall, he had read about Hottel's early experiment with the water-filled wall.

"He decided it didn't work," Baer said. "But that was because he didn't do it the right way. And he didn't keep on. If he'd been some crackpot, he might have.

"The crackpot is ready to explore new territory without government funding. There's gotta be room for crackpots in any society."



Who were some of the crackpots in solar heating? I asked.

"Well, like me," he said.

Many large companies leaped into solar heating after the oil embargo, picked up government grants, and started out trying to apply very sophisticated, expensive engineering to the problem of heating homes. GE went so far as to assign solar operations to its space division. But a number of companies that began this way have since changed their approach and are now working on conventional designs.

The so-called "high-tech" approach generally involves trying to increase the efficiency of a system by getting the maximum amount of heat out of each square foot of collector. Some gadgets that usually accompany this approach are "selective surfaces" (collector coatings which absorb more sunlight and emit less thermal radiation than ordinary black paints) and "evacuated vacuum tube collectors" (in which tubular absorbers are insulated by vacuums maintained around them). Such high-efficiency devices invariably cost a great deal. The rationale for using them is that high efficiency leads to reduced collector size and thus to reduced materials costs. Maybe someday the approach will yield economical systems, but it hasn't so far. Moreover, efficiency is a difficult concept to apply to solar heating. For instance, when it is cold outside, many eff[illegible]t high-temperature collectors lose more heat than inefficient, low-temperature ones, in which case the low-efficiency collector is the more efficient.

One thing many promising solar-heating systems seem to have in common is that their inventors are not connected with big companies. For the most part, they are a gang of small entrepreneurs and lone wolves. They have worked with their own money; only a few have gotten support from ERDA. Perhaps that gave them a head start in the quest for economy.

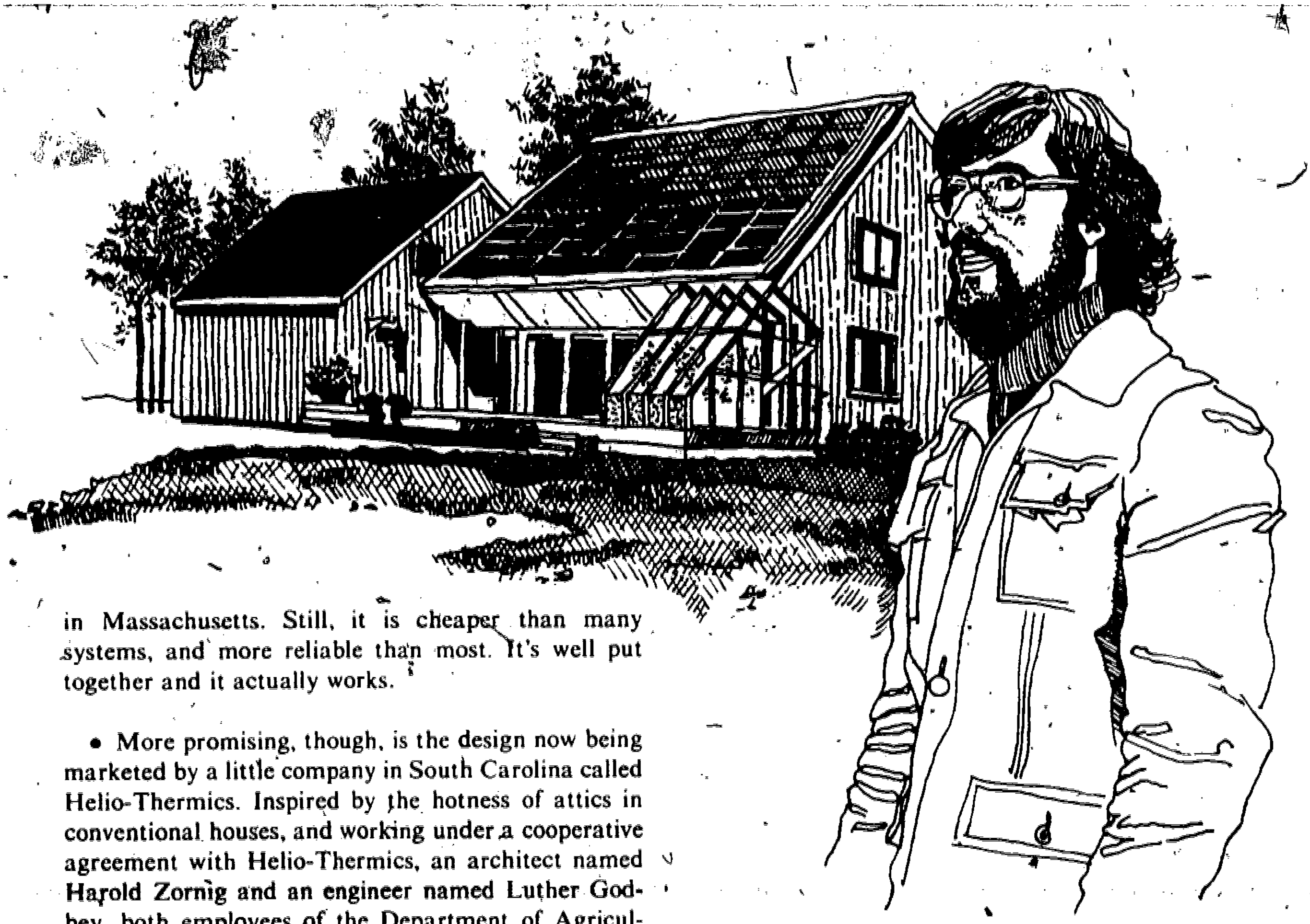
Traveling around, talking to solar people on the phone, I kept hearing of wonderful systems, so many I could not examine all of them. But here is a sampler of possible Henry Fords and their solar-heating Model T's:

- Steve Baer and his zomes. Although his audience may be limited today, he is by no means finished with inventing.

- Then there is the man who taught Baer some tricks: sixty-eight-year-old Harold Hay. Fifteen years ago, while working for the State Department as an adviser on building materials to the government of India, Hay hit upon an idea for both heating and cooling residences, a sim
sign that would employ "a mini
modern Western technology." Hay's flat-roof
Therm house has ponds beneath the roof, a
swimming pool contained in large plastic bags
little devices make the system work. Powered by
quarter-horsepower electric motor; the insulat
panels open on winter days to catch the sun an
on winter nights to keep the heat in. Warmt
down from the water bags through the metal ce
the house. The first home he built in the Unite
has 1140 square feet of living space. In the wi
1973–1974 the house was 100 percent solar
and it can get through four cold, sunless Janua
Admittedly, it stands in California between Sa
cisco and Los Angeles, where the winter isn't
On the other hand, the house is versatile. On s
days the roof stays closed and opens up at nigh
heat from the house accumulates in the ponds
and at night it passes out to the sky by convect
radiation. The result, according to the rep
tenants, is marvelous air-conditioning. The sy
also cheap—$5000 for a 1000-square-foot hou
less if several are built simultaneously. Hay h
developed a Sky-Therm home for northern cli

- Felix Trombe of France, another of the
pioneers," has approached space heating with a
the Trombe Thermosiphoning Wall. A black-
concrete wall faces south, behind two layers o
There are openings at the top and bottom of t
Cold air comes from the house through the
opening, is heated in front of the wall, rises as
will, then passes through the top opening and b
the house. The system appears to be cheap, lik
and in one house in France, it has delivered 6
percent of the necessary heat. The design
though, from the ironic deficiency of too ma
houses. It doesn't let much sunlight in: there's
where one would like to have windows.

- Many of the hurdles solar heating has
mount are related in one way or another to



Bruce Anderson and Goosebrook House

in Massachusetts. Still, it is cheaper than many systems, and more reliable than most. It's well put together and it actually works.

- More promising, though, is the design now being marketed by a little company in South Carolina called Helio-Thermics. Inspired by the hotness of attics in conventional houses, and working under a cooperative agreement with Helio-Thermics, an architect named Harold Zornig and an engineer named Luther Godbey, both employees of the Department of Agriculture's Rural Housing Research Unit in South Carolina, designed this hot-air system. *Mother Earth News* has gushed over it. Indeed, it looks like one of the cheapest of all the heating systems available today. Sunshine gets into the Godbey–Zornig house through a double-glazed, translucent, fiber-glass roof, and strikes sheets of black-painted plywood located in the attic, heating up the air. Some heat moves into the living space by itself. There is also a one-half-horsepower blower, hidden in a closet and activated by a device which Helio-Thermics likes to call "a computer" and which Godbey describes as "just a plain old solid-state control device." The blower drives air through the attic and down into the storage system, a bin containing forty tons of railroad ballast and located directly beneath the house's main floor. The system has worked well, delivering about 75 percent of the first Helio-Thermics house's necessary heat during an average 40° F winter in South Carolina. The "incremental" cost of this system in the little prototype house, which has 1000 square feet of floor space, was less than $3000. For a few hundred dollars more, the system can also provide 50 percent of the energy for a home's hot-water heating. These figures, which come from the USDA, probably make this system economical today. The trick to cutting incremental cost, Luther Godbey told me, is designing the system right into the house, using the solar collector to replace the roof, placing the store right in the foundation. He and Zornig also strove to minimize the use of expensive components such as ductwork.

The system is a testimonial to the low-technology approach. Luther Godbey drawls, "I think the best thing you can say for solar energy right now is simplicity." Interesting that the idea came from a rural branch of the USDA and was financed by a local builder, not from the public coffers. Interesting that nothing half so economical has come from the National Laboratories, which have received millions in ERDA solar-heating research grants.

- A list of solar-heating wizards and important plodders ought to include at least several dozen more names than the following: Shawn Buckley of MIT, whose "thermic diode" could solve a lot of problems for some active water systems; Malcom Wells in New Jersey, who may be the world's best designer of solar-heated houses located partially underground; George Löf of Solaron in Denver, one of the grand old men of the trade and a pioneer in active hot-air systems; David Wright, who has roamed the Southwest designing dozens of solar houses, including many strange and wonderful-looking passive ones. There is Norman Saunders of Weston, Massachusetts, who stands among the geniuses of the passive approach, eschewing moving parts. His latest design is the Saunders Solar Staircase, which consists of a translucent plastic roof under which hangs a tier of steps, shiny on the tops and transparent on the vertical faces, and precisely sloped and spaced so that summer sun can't get through but winter sun can. There is also Bruce Anderson, more a synthesizer than a pure inventor. His new Goosebrook House in New Hampshire is quite expensive—it sold for $70,000 four days after it went on the market, the entire solar heating system cost about $8000. But it's a spacious home, designed to be a showplace. It weaves several strands together, a greenhouse (for heat as well as growing things), an active water roof collector system, and unobtrusive passive features, such as a set of doors which slide on tracks out of the garage to insulate the southern windows after nightfall. It is the nicest, attiest solar house I've seen.

T[illegible] ate is honorary [illegible] Catawba University where he got his undergraduate degree in physics and math; he says he learned his engineering in the Coast Guard.) No list can exclude Thomason. Quite literally, the man demands attention.

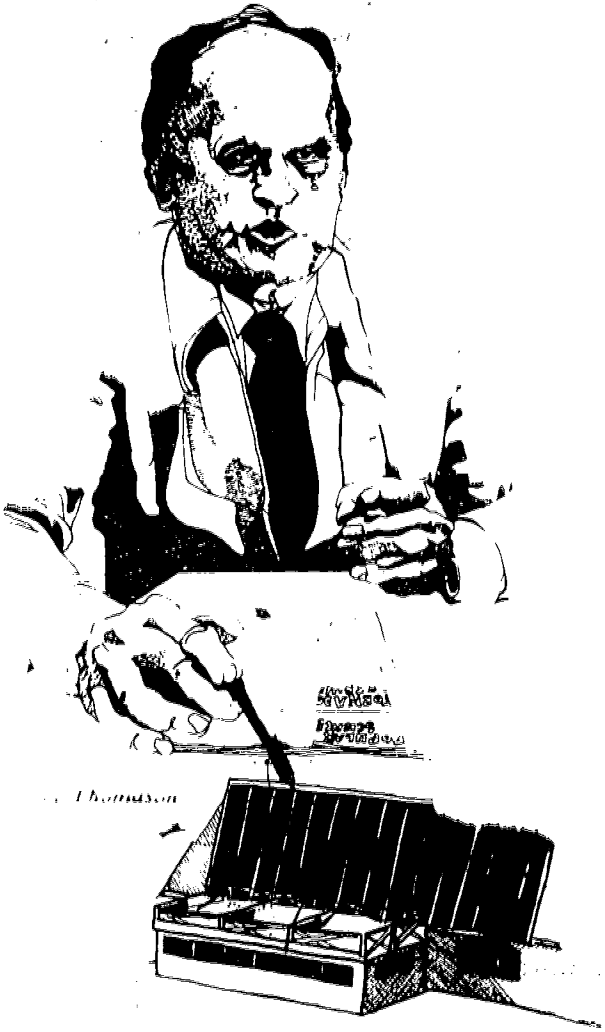
Thomason's career began serendipitously. "This is a true story," he told me. "It was in the Reader's Digest. The New York Times likened me to Sir Isaac Newton." It was 1956, as Thomason remembers it, back in the middle of North Carolina farm country, a land of sudden summer thunderstorms. "The old barn still stands there," he recalled. "It had a rusty roof that made the difference." A hot day, sun beating down on the barn roof, Thomason out near the barn. Suddenly huge clouds rolled in. "Down came the rain. I ran under the overhang on the barn roof and I thought to myself, 'Gosh, that['s] warm water.' I looked up to see where it was comin' from. Right off the old barn roof. Instantly—of course it's what we call a flash of genius—I realized what was goin' on. 'That's a solar collector there!' I just dashed under the overhang. Cold water had been fallin' on my head. Now here came warm water on my head off the barn roof. That was the original inspiration."

Like Norman Mailer and Browning [illegible], Thomason often refers to himself in the third person. He writes in his newsletters: "THOMASON SPEAKS OUT and writes about EXXON and government agencies who are discouraging solar heat." Or, "DR. THOMASON WILL CONTINUE HIS ONE MAN (ONE FAMILY) CRUSADE TO FORCE HUD, FEA, ERDA AND THE BIG OIL COMPANIES TO STOP MISLEADING THE AMERICAN PUBLIC. THEY LEAD YOU TO BELIEVE THAT SOLAR HEATING AND AIR-CONDITIONING APPARATUS IS EXPENSIVE. THOMASON HAS THE PROOF. THOMASON'S 'SOLARIS' IS VERY LOW IN COST."

"He's his own worst enemy," many say. Steve Baer is one of the few people in the business who doesn't take strong exception to what is known as "Thomason's style." Baer feels he understands. Thomason has gotten a lot of good press lately, his disciples now include a number of private builders, and ERDA is spending $194,000 to test a Thomason home. But it wasn't always so. He has had a long hard time getting people to take him seriously.

Skepticism about Thomas[illegible] ty because of his style, but also because of the claims that he makes for his brainchild. He says that at a cost of about $3500 his "Solaris" design will provide 95 percent of the heat for a three- or four-bedroom home in a moderately warm climate. In what he calls "bitter cold Massachusetts" or "bitter cold Minnesota," he says he can get you 75 percent for $4500. This is about half the cost of most good active systems, and the performance he boasts of is 20 or 30 percent better than most.

His collector is essentially a corrugated aluminum barn roof, painted black and covered with a single



Thomason

layer of glass, which is about as simple and cheap as an active solar collector can get. Water flows in a thin stream out of holes in a pipe that runs along the top of the collector. The water travels down the corrugated valleys into a gutter, then down to the basement into a 1600- or 2000-gallon water tank surrounded by stones. The water heats the stones, a blower takes the heat from them and sends it into the house. The U.S. Department of Agriculture and Professor J. Taylor Beard of the University of Virginia have tested the Thomason collector. "The results of those tests shocked the nation," Thomason told me. In fact, what they showed was that Thomason's collectors are quite efficient, when they're operated at low temperatures. And that is how they operate; that's the trick, according to people like Bruce Anderson, who is executive editor of *Solar Age*, author of the new book, *Solar Energy*, and a designer, and who installed a Thomason-style collector on the Goosebrook House. What's more, this collector seems to be virtually indestructible.

I heard allegations that high humidity and mold on northern interior walls afflict some Thomason houses. But a family in Minnesota told me that their Thomason home was fine and cozy. They said they used only $25 worth of gas for their back-up heating from February 25 to March 25, 1977, which was a particularly frigid month up north. The builder said the system cost about $6000, more than a Thomason unit should, according to Thomason But the house and system are large, and the builder says he was a novice at solar heating and made some costly mistakes

Rhett Turnipseed an official in ERDA's solar division, checked out this Minnesota house. "I keep waiting for the other shoe to drop," he told me. "Thomason's system makes real good engineers climb the walls. It's a Pinto, not a Cadillac It's like a Model A, it'll rattle around some, but the data coming in looks good. He's a little guy with a widget that works"

Referring to the now well known story of the old barn roof, and to the article which likened Thomason to Sir Isaac Newton, Steve Baer said, "Well, it took Newton a whole heavy apple With Harry, it was just a few raindrops"

An astonishing gizmo

Most people who are [illegible] refinement of solar heating do not anticipate a new piece of hardware that will at once solve problems of retrofit, cost, performance, and durability. If there is an astonishing gizmo coming, it probably belongs to another solar technology: photovoltaics.

It is impossible to explain the conversion of solar radiation to power without recourse to specialized language, and the specialized language itself is sometimes a disguise for a highly mysterious process. As one science writer has put it, "Photovoltaics is basically an incomprehensible drama." It is perhaps enough to say that when sunlight strikes the crystalline forms of certain elements—silicon, for instance—it frees electrons from their places in the atomic structure and thus generates a small electric current.

The potential applications of photocells appear to be vast, ranging from central power stations to neighborhood photovoltaic plants, perhaps even to individual energy systems for single-family dwellings Many who dream of local or personal self-sufficiency in energy—a dream which is generally described as "pulling the plug on the utilities"—look toward photocells with interest and anticipation, and so do many solar-heating architects and engineers. "Hybrid" systems gathering both electricity and heat for houses are being tested. They work. The problem is that energy systems employing photovoltaic cells always end up costing a great deal more than the houses they're attached to. So far, the only practical uses for photovoltaics have been on spaceships and buoys located in remote archipelagoes. Though photocells proved themselves to be reliable and durable in those applications, power from a photovoltaic system today would cost twenty, thirty, or maybe even forty times as much as electricity from a conventional nuclear system

Photo-electric cells produce direct current, and since American homes now run almost exclusively on alternating current, a converter must be used Storage is a more severe impediment; the absence of a cheap way to store electrical energy afflicts the entire power industry, and a great deal of research is now under way The space station approach to photovoltaic systems is in essence a plan to get around the storage dilemma by putting the cells in a place where the sun always shines, but that may be the most expensive of all possible solutions Some researchers throw up their hands over storage and say that photovoltaics can never be more than a supplement to conventional and nuclear central power station energy Some look to flywheels and to such ideas as storing electric power in underground caverns in the form of compressed air Some feel the answer lies with the good old lead acid battery, or maybe with the sodium-sulphur high-temperature battery, which is being developed for electric cars Today, the wiring and packaging of cells accounts for about half of their cost. At the one plant I visited, assembly and packaging were being done laboriously, by hand. Cheaper techniques must be applied Inexpensive ways of installing arrays of cells must also be found, and ultimately backyard inventors such as Thomason and Baer might be enlisted in that effort

Looming over all other impediments today, however, is the cost of the photo-electric devices themselves, a problem for solid-state physicists, not for solar-heating wizards. The material used most often for the absorber plate, which is the cell's main component, has been silicon, the second most abundant element on earth, after oxygen. But producing single-crystal silicon hasn't been cheap. In the past, a high-purity, cylindrical ingot of crystal silicon was drawn from a crucible and then cut like a bologna in sheets a few thousandths of an inch thick. It was slow work. A lot of hand labor was required. Up to 75 percent of the silicon was lost in the form of expensive sawdust. Then, several years ago, Tyco Labs in Waltham, Massachusetts came across a way of "growing" the silicon crystal in a very thin continuous sheet, which could be scribed and cut with relative ease and little waste. The process is now being refined by Tyco Labs Solar Energy Corporation, 80 percent of which is owned by Mobil Corporation. Mobil-Tyco's work is considered to be among the most promising approaches in the photovoltaic field, but there are many others. Backed partly by federal money, about fifty organizations have joined the search for a cheap photocell. Investigators include universities, national laboratories, small companies, and large concerns such as Motorola, RCA, Shell, Exxon, Texas Instruments, and Rockwell International.

I talked to representatives from Mobil Tyco, from ERDA's solar division, from Solar Power Corporation (an Exxon subsidiary), from Lincoln Laboratory. Optimism was general. The cost of photo-electric cells has already come down from about $50 per watt to about $15, and some researchers claim that they'll have the price down to $2 a watt within the next two years. ERDA has decreed that the cells will cost fifty cents a watt by the mid 1980s and something like thirty cents in the 1990s. Even at $2 a watt, large new markets should open up. Opinion divides on the question, but some researchers feel that at thirty cents a watt photovoltaic cells could grab a sizable chunk of the residential market.

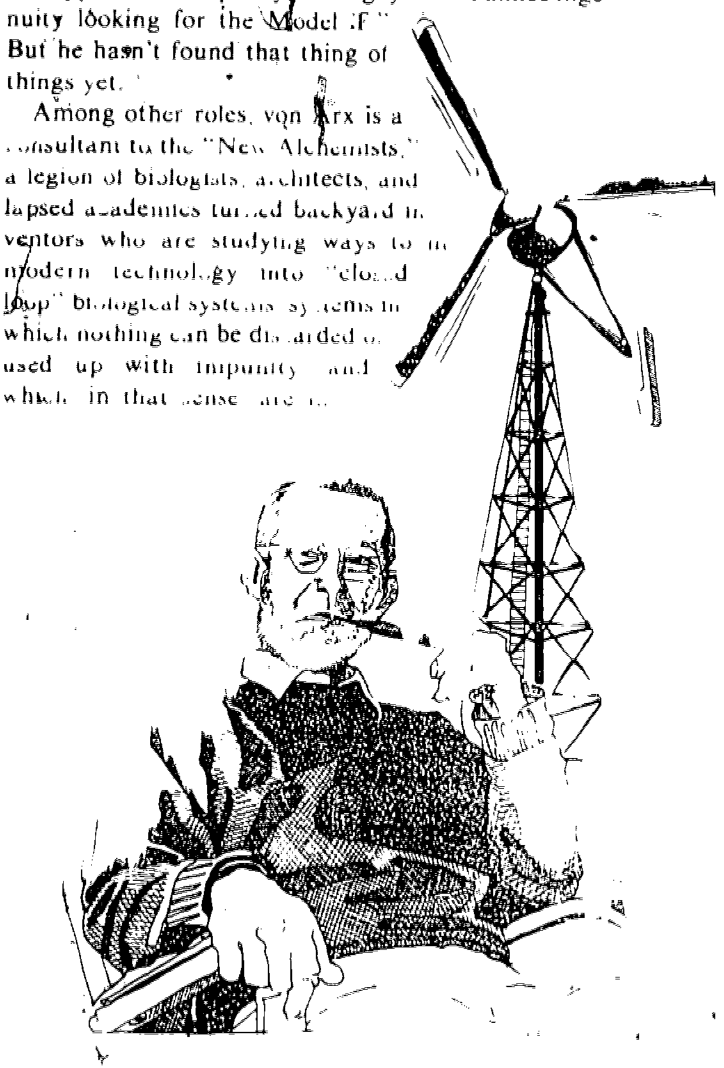
The economics of the breeder [illegible] fully as uncertain as those of the photocell, and compared to nuclear fusion, which has yet to be proven feasible even in a laboratory, the photo-electric art is far advanced. Nevertheless, in fiscal 1978 the government will spend six times more money on fusion and twelve times more on the breeder than on photocells. And if the $60 million allocated to photovoltaics in 1978 is too little, as some researchers say, ERDA will still have trouble handing out the loot. ERDA has only four people working in photovoltaics. Given the rules of the Washington funding process, four is a pitifully small number to go with $60 million.

A solar philosophy

In a favorite vision, the scientist William von Arx foresees a change in the hardware hanging from the electrical transmission towers that stride in all directions across the United States. These tall backbones of the central-power-station approach to heat and light are stripped of their high-tension wires. Von Arx imagines windmills attached to them instead.

A senior scientist at the Woods Hole Oceanographic Institute, von Arx has been a professor at MIT and a consultant to a wide variety of scientific agencies such as the National Science Foundation, NASA, and the National Academy of Sciences. Changing the direction of his research every ten years or so, "to avoid going stale," he has worked "in and between" the fields of astronomy, meteorology, geology, and oceanography. "I've wanted to understand the physical environment of man," he explains. This inquiry has led him finally to the all-embracing field of energy. He has approached it, partly, "as a guy with Yankee ingenuity looking for the Model T." But he hasn't found that thing of things yet.

Among other roles, von Arx is a consultant to the "New Alchemists," a legion of biologists, architects, and lapsed academics turned backyard inventors who are studying ways to fit modern technology into "closed loop" biological systems, systems in which nothing can be discarded or used up with impunity and which, in that sense, are [illegible]



tended as metaphors for the earth itself. At a cost of about $1000, von Arx has built a solar pond on the field behind New Alchemy East headquarters, near Falmouth on Cape Cod. This shallow concrete pool, which is filled with water, brine, and particles of coal, is about fifteen feet in diameter and produces some four kilowatts of thermal energy by just sitting in the sun enough heat, von Arx maintains, to warm about a third of a typical Cape Cod house. But the pond idea is old and already well-investigated, principally by Dr. Henry Tabor of Israel, and its possible applications appear to be severely limited. Von Arx has also drawn up plans for a community heating system, suitable for suburbia, which employs underground aquifers to store summer heat for winter use. A group in Texas is working on this, too. It is a promising idea, yet untested. Today, von Arx remains primarily a theorist.

He lives a few miles from his pond in an airy modern house surrounded by vegetable gardens, on a hilltop overlooking Buzzards Bay. An eleven-inch telescope is set up on the grounds. The morning of the first day of last summer found the windmill near his front door chattering away in a gentle southwester and von Arx inside listening to a public radio broadcast of the Latvian celebration of the summer solstice, an ancient solar rite. He is a man of medium height, vigorous and muscular though a prodigious smoker of Pall Malls. He will not name his age. "Let's say I'm over sixty." He was wearing shorts and sandals, a crew cut, and a close-cropped white beard. Von Arx has a way of making his eyes appear to grin. He uses this gesture and other more conventional smiles to qualify statements like these: "I'm worried about the long-term future, *if* there is to be a long-term future." Or "The threat of plutonium is far mightier than the media has led us to believe." Or, applying the nautical phrase to energy: "It's time to order a change of course. We got [illegible] ahead."

Amory Lovins, who has spent [illegible] hours on the phone with von Arx, writes of "a sub-capitalist social movement" which has begun "a reexamination of the industrial ethic." In a phrase which his adversaries love to mock, Lovins describes this movement as "camouflaged by its very pervasiveness." Indeed, it is hard to know just how pervasive such a movement might be. But its existence is obvious, especially at gatherings like the "Toward Tomorrow Fair." Uninterested in working hard to convince the [illegible] convinced, von Arx stays away from such events, but he is one of this amorphous "movement's" eloquent and credible spokesmen. He says he is looking at energy "from a global point of view." His sinuous argument reproduces the Lovins and the E. F. Schumacher small-is-beautiful line, but from a naturalist's and space explorer's perspective. Ever since the Crusades, von Arx believes, mankind has treated the planet as if it were "an open ecosystem." To him, nuclear energy is merely another attempt to perpetuate this dangerous violation of "the limits to natural abundance." We must use less energy absolutely, he feels, and much more of what we use must be of the renewable kind. This would be the ideal: "To live by the natural regimen of the sun."

Even if the short-term contributions of solar craft are small, technologies such as solar heating aren't likely to be insignificant. Bruce Anderson contends, "Out of solar heating comes energy conservation." The effort to warm living rooms with sunshine does seem to have given solar heating engineers and people who live in solar houses a new awareness of energy, how hard it is to gather and contain, and how precious. "In*sul*ate before you in*sol*ate," has become the first principle of the trade.

Revelations come from solar heating. I have in mind the sort of thing which the sixty-five-year-old entrepreneur John Bemis told me while we were admiring one of his elegant, expensive, solar-heated Acorn Structures. "It's fantastic what volumes of energy we're used to having in a house," mused Bemis. "You know, having a two-gallon-an-hour oil furnace in your basement is like having a bulldozer down there. And that's a pretty powerful piece of machinery, a bulldozer."

But [illegible] the ultimate practical significance of solar heating and of the other solar arts, their philosophical importance is easier to see. Many well-informed participants in the energy debate, such as the ardently pro-nuclear Representative Mike McCormack, hold that solar and nuclear technologies are not mutually exclusive. We must look to both in the future, they say, and maybe they are right in practical terms. But to solar theorists the approaches to nature which these two technologies represent are not compatible.

On August [illegible], President Truman stirred the nation with the news of the bomb that had been dropped on Hiroshima. "It is a harnessing of the basic power of the universe. The force from which the sun draws its power has been loosed against those who brought war to the Far East." That was the beginning of the age of nuclear power. The idea of using this source of destruction for peaceful purposes had been made incredibly alluring. Nuclear power would be an atonement, a way of forgetting Hiroshima. But now the solar advocates have redefined the issues. In their rhetoric solar technologies seek only to collect the energy which nature has provided, while nuclear explorations have sought to penetrate the secrets of the sun and have set about recreating versions of the solar furnace on earth by smashing atoms. To the solar advocates, nuclear energy stands for an arrogant, aggressive attempt to master nature, while the solar approach is a humble, passive effort to make peace with the planet.

Outside Bill von Arx's front door the little windmill is whirling in the freshening breeze off Buzzards Bay. Von Arx stands contemplating this piece of machinery, which looks like the skeleton of an airplane with the propeller still intact, mounted on a tripod some ten feet tall. "I think it's beautiful," he says. And then he points up toward the morning sun, which supplies the force that drives his windmill, and grinning, he explains, "That's a safe distance for a nuclear reactor. And it runs unattended, you see." ☐