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, and 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 Accurex 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