Energy Storage and Solar Power: An Exaggerated Problem

What do you do when the sun goes down? is a question often asked about solar energy. During cloudy days, long nights, and times when the wind ceases to blow, what is to be done for power? The answer, according to conventional wisdom and seemingly impeccable logic, is to build an auxiliary system that will store energy when the sun is out or the wind is blowing, and use the stored energy when they are not. The problem with that answer is that storage systems available today tend to be cumbersome, costly, and less than perfectly efficient. When their expense is added to the cost of a basic solar energy or wind system, which is no more than marginally economic in most regions, the total price often becomes exorbitant.

For this reason, the problem of energy storage is often characterized as a major obstacle to the widespread use of solar energy. The magnitude of the perceived problem has heavily influenced the public debate over the role that solar energy can play. It has been used as an argument for holding down solar research support, on the grounds that the cost of storage limits the potential use that can be made of solar energy for the indefinite future. It has been cited by government administrators as a prominent reason for giving strong support to certain solar technologies—not intermittent in nature—which might otherwise be difficult to justify. Even the prospect that the storage problem might be solved has been turned against solar energy programs, with the argument that a technical breakthrough that produced cheap storage would be more to the advantage of nonsolar technologies than solar ones.

These arguments may contain a grain of truth, but the conclusions are nevertheless open to challenge. Solar energy storage is a complex problem, and the importance of storage—especially for uses in the near- and intermediate-term future—may be overstressed and misunderstood.

One reason storage springs to mind when solar energy is mentioned is that solar energy is often associated only with the conversion of sunlight directly into thermal energy or electricity. A few years ago heating and cooling of buildings was the cutting edge of solar technology, but today solar technology includes a broad spectrum of concepts that are greatly different in their requirements for storage. Plant matter or biomass, a long neglected energy source that is now the beneficiary of a reorganized program under the heading of solar energy research, provides energy in a form that is ideally storable for long periods. Wind power is another form of indirectly derived solar energy which, even though it is intermittent, is available more of the time—day and night—than direct sunlight in many regions, and wind is particularly amenable to creative solutions to the storage problem.

Natural Solutions

Energy storage is more nearly indispensable for solar water heating, heating of buildings, and production of heat for industrial processes. But even in these applications there may be natural solutions, such as "passive" heating and cooling of homes, that do not require storage as a separate system. This is an approach in which windows and skylights collect solar energy and normal building materials serve the storage function. There may also be economic breakthroughs in thermal storage, possibly through annual storage on a community-wide scale, that could reduce costs and dramatically improve the reliability of solar heating.

Another factor that may work to subtly reduce the storage problem is any movement in the energy economy toward greater coordination of the sources of energy supply and demand. It would be naive to suggest that people will easily give up the prerogative of having energy when and where they need it, but the flexibility that has occurred in an era of cheap energy may be changing. Time-of-day electric pricing, already introduced in some areas, is one evidence of this. The utilization of computer systems that automatically manage the energy load in large office buildings is another. Such changes, although they may be exceedingly gradual, will tend to make the alternatives to solar energy a little more intermittent themselves and may create a social climate in which solar energy becomes more acceptable used "as is" rather than with storage.

The major reason, however, that storage may not be a solar sine qua non for the immediate future is that there are no fewer than three configurations in which solar power sources can be integrated with present energy systems—particularly electric systems—so that new bulk storage is not required.

Overlooking these alternatives has led to a confusion of solar energy's near-term and long-term needs for storage. Even at wildly optimistic rates of growth, solar energy's contribution will be a relatively small perturbation on the national energy picture until the turn of the century. In such circumstances, the traditional energy system can be used to compensate for the fluctuations of solar sources. So long as oil is a major component of the energy supply and is wastefully used where other fuels would suffice, solar energy systems can profitably be used to displace oil when the sun is out and can be left idle when it is not. The national energy system is a well-integrated complex in which no element is 100 percent reliable; the entire system derives its reliability from redundancy. Since large blocks of electric power are routinely transmitted considerable distances, the electric network is particularly well suited for smoothing and balancing solar power fluctuations. If the solar-derived energy grew to too large a fraction of the total, the overall stability of an electric network might be adversely affected. But a number of studies indicate that this limitation is unlikely to be a problem until the solar power penetration reaches 15 or 20 percent.

A strategy using solar energy in hybrid systems without storage would appear to be well suited to the upcoming decades, when solar energy usage may grow but must remain less than about 25 percent of the total because the turnover in systems and equipment is too slow for more rapid change to occur. It is only when the consumption of oil falls significantly and the penetration of solar electric technologies into the national electric grid becomes substantial that cheap energy storage will be badly needed.

Not a Near-Term Problem

Thus, solar energy's long-term problem has been somewhat unfairly portrayed as an obstacle to its development in the near term, when, in fact, there are many other options. It is particularly ironic that some of the critics who say that solar energy cannot supply more than 1 or 2 percent of the country's energy by 2000 also cite storage as a critical problem. (At that low a growth rate, storage would not become a serious

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problem until the 22nd century.) The danger in focusing on the wrong time horizon is that solar energy may make less contribution than it could during the years immediately ahead.

The first alternative to building expensive new storage systems in the near term is to use existing storage systems, namely hydroelectric installations. By holding back water that would otherwise be flowing through the sluice gate of a hydroelectric dam, energy can be stored in one part of an electric network while a solar energy system (perhaps a photovoltaic, wind, or solar thermal system) is producing energy in another part. The United States has 59,000 megawatts of hydroelectric capacity and an additional 10,000 megawatts of pumped storage capacity. Pumped storage facilities consist of a pair of reservoirs, the upper one being filled with water pumped up from lower levels at times of minimal electric usage. Although half of our hydroelectric capacity is in the three West Coast states (the largest single project is the 4000-megawatt Grand Coulee Dam on the Columbia River in Washington State), hydroelectric dams are found in 47 states. New York State has a particularly large resource, with an extensive network of small dams besides the one at Niagara Falls.

Little alteration, if any, is needed to utilize hydroelectric projects for storage. In instances where the plant was already being used at full capacity the installation of extra turbines ("overmachining") would be needed. But many facilities regularly run at much less than full capacity (Grand Coulee generally uses only about half its 21 turbines), so there would be extra capacity available to produce a surge of power when a wind or solar system was down. Although this is not literally energy storage, it has the same effect as if wind or solar energy had been used to pump extra water into the hydroelectric reservoir for release later.

A prominent proposal to use this sort of system in the Rock Mountain region has been made by Stanley Hightower, at the Bureau of Reclamation in Denver. After analyzing the extra capacity available from the dams in the Colorado region, particularly the Flaming Gorge and Glen Canyon dams, Hightower and Abner Watts concluded that the available hydroelectric storage capacity was sufficient for a 98-megawatt system of large wind turbines. To make use of the flexibility that the electric network offers, Hightower suggested that the system's 49 wind turbines be located in a site of particularly high annual wind speeds, near Medicine Bow, Wyoming.

A different sort of proposal for a new wind, old hydroelectric project is under consideration in New York state by the Niagara Mohawk Power company. In that instance, the wind system would not be hooked directly into the electric grid. Situated near a small hydroelectric plant on the Salmon River east of Lake Ontario, the proposed Niagara Mohawk wind-hydro system would pump water back up into the reservoir for use again and again. In that region, the winds and the electric demands both peak in the winter, when the water levels are low. By recycling water, the storage necessary to make wind a reliable power source can be achieved, according to S. Eskinazi and J. Brennan at Syracuse University. There are about 75 similar small hydroelectric plants (averaging 10 megawatts) in the region, according to Eskinazi.

6000 Megawatts of Hydroelectric Storage

How much of the installed hydroelectric capacity could be used as storage for alternative energy sources is an open question now, since the question has not been systematically attacked. Hightower found, after a careful review of all requirements, that about one-tenth of the Colorado regional capacity was available. Since his approach was quite conservative, it may not be a bad rule of thumb, recognizing that some facilities may allow more capacity and others less. According to that rule, there would be at least 6000 megawatts of storage capacity at present in the United States.

Hydroelectric capacity has not stopped growing. New projects in the works in the United States will add up to 5000 megawatts. Canada is one of the world's most extensive users of hydroelectricity, and one new project, at James Bay, may eventually grow to 10,000 megawatts by itself. Small hydroelectric dams could be built at as many as 47,000 sites in the United States, producing 54,000 megawatts, according to a recent survey by the Army Corps of Engineers. If new solar sources were wisely coordinated with existing (and planned) hydro projects, solar energy could go quite a way before the storage potential was exhausted. But the use of existing storage is only one option.

Another option is to use solar energy systems with fossil fuel backup systems, thus saving fuel whenever sun or wind is available. Fossil fuel backup systems are quite inexpensive compared to storage systems, so this mode of operation—usually called a fuel saver mode—makes good sense in a time of abundant but expensive oil. Numerous analyses indicate that it is generally the first mode of solar energy deployment that will break even.

In a home, the fuel saver mode might mean using a solar water heater with a backup of gas—a symbiosis that is favored by a number of gas companies. It might also mean using a solar heating system with an oil furnace as a backup. In an industrial application, where solar thermal systems would be used to produce steam or process heat, it would mean using an oil-fired backup system instead of storage. This symbiosis is particularly attractive because solar energy systems have high capital costs but no fuel requirements, while oil backup systems have very low capital costs and high fuel costs. In many cases, the oil backup system already exists as the present heat or steam supply, thus further lessening the investment required.

In much the same fashion, solar energy units can be tied into an electrical grid so that they operate in a fuel saver mode. Wind power, because it is much the cheapest source of solar electricity, is currently best suited for such a mode. The wind system would be designed to supply power that would otherwise be produced by the fossil-fueled (particulary oil-fired) units that the utility uses to produce electricity during periods of peak and intermediate demand. The wind system would not replace any conventional units in the fuel saver mode. The utility would maintain a full complement of intermediate and peaking units to serve as backup when the winds were calm. The benefit would derive from the fuel saved when the winds were blowing.

Restricting wind (or other solar electric sources) to peak and intermediate load periods sounds as if it might severely limit the solar energy contribution. But 40 percent of U.S. electricity is produced by intermediate and peaking units, and various studies show that wind operated in a fuel saver mode could produce 5 to 6 quads of electricity by 2020 (*Science*, 12 May 1978). About half of the U.S. utilities have their peak loads in the winter, and the other half (generally those in the sun belt) have load curves that peak in the summer. Optimal matching of different solar sources to different utility load curves is a subject that deserves much more analysis. But it appears likely that wind power (which generally shows a higher flux in the north) will be most suitable for winter-peaking utilities, while photovoltaic or solar thermal electric installations (which benefit from the maximum solar insolation in summer) will be most suitable for summer-peaking utilities.

Rather than being linked though the electric grid, the fossil fuel backup for a solar system could be located at the same site as the solar electric plant and possibly accrue additional savings through common usage of certain pieces of equipment. This is a feature of a solar thermal electric design proposed by the Electric Power Research Institute, in which the oil-fired backup would use the same turbine as a power tower system. EPRI found that the backup capability would add only $4 per kilowatt to the cost of the system (which was $1500 per kilowatt), and would obviate the need for short-term (3-hour) storage, which would cost $180 per kilowatt and provide far less reliability.

Reliability Through Interconnection

It is not clear, however, that the only benefit from a significant number of solar electric units would be fuel savings. Reliability might also be increased. Power generated at a particular site is likely to be unpredictable, but if wind or photovoltaic units were dispersed over a number of sites far enough apart that the natural energy flux was uncorrelated, the output of the connected array would be considerably more predictable. The effect of interconnection would be to average the fluctuations at different sites, with the result that the interconnected system could be counted on to reliably produce at some fraction of its potential capacity most of the time.

Again, wind is the resource for which this possibility has begun to be investigated, and preliminary indications are that—depending on the region—an interconnected wind system may earn a "capacity credit" equal to 10 to 30 percent of the total wind system capacity. This means that without any storage, a large wind system that produced 500 megawatts at peak might be able to replace 50 to 150 megawatts of conventional capacity in an electric grid.

The data base for wind correlation effects is modest, but the few cases that have been studied so far indicate that interconnection yields considerable improvement. J. Molly at the Building and Construction Research Institute in Stuttgart, Germany, has studied the effects of connecting a number of windmills placed at various weather stations in West Germany and found that whereas one wind machine might be idle 35 percent of the time, the entire network would be idle less than 1 percent of the time. More importantly, Molly found that the hypothetical network, which consisted of 18 sites with an average spacing of 240 kilometers, produced more than half its average power output 65 percent of the time. A single unit met the same criterion only 35 percent of the time. This figure is of interest because 65 percent is approximately the reliability rating of a large conventional plant. Similar results were found by C. G. Justus at Georgia Tech, who analyzed National Weather Service data for New England and the Midwest. Justus found that for each 1125-kilowatt wind generator in a connected system, 200 kilowatts of power was available 77 to 93 percent of the time.

The actual calculation of a capacity credit is more complicated because it depends on the characteristics of the existing utility system as well as those of the wind system. Using a system reliability model commonly employed by utilities, Ed Kahn at the Lawrence Berkeley Laboratory studied the amount of capacity credit that could be relied on in the California networks. He found that for the installation of multi-unit wind systems sized up to several thousand megawatts, the credit would be 17 to 26 percent. But as more hypothetical wind capacity was integrated into the system, the additional capacity credit declined, because there was a statistical limit to the amount of power smoothing that could be achieved. When wind power grew to constitute 25 percent of the system, Kahn found that the capacity credit for new machines dropped to zero. (The value of a wind system as a fuel saver would be governed by different considerations and would not necessarily cease at the same point.) Thus, his studies indicate that the strategy of interconnecting intermittent sources through a grid to circumvent storage is particularly applicable when solar sources make up a reasonably small fraction of the energy mix. It is therefore ideally suited for the upcoming decades.

Storage Research for the Long Term

None of this discussion should be taken as an argument against storage research. The use of intermittent energy sources is likely to grow. If the ensuing energy debate leads to a public consensus that the country should move toward a predominantly solar economy, energy storage will become crucial. Even in the near term, storage is essential in many remote areas and for applications where the source is out of synchronization with the load. Furthermore, it is undoubtedly an oversimplification to portray the alternatives as either no storage or much storage. The growth in the use of storage is likely to be gradual but continuous, not only because of the needs of solar energy but also because of the demand and price structure of electricity.

Rudimentary energy storage is already available. Water tanks, rock beds, and specially designed pools can be used for thermal storage. Pumped hydroelectric systems and batteries can be used for electric storage. For annual storage, which means saving heat or "coolth" from one season to another, the use of larger-than-normal units in single-family houses is already being tested, and much larger storage systems—using lakes, reservoirs, or underground aquifers—are being proposed for small communities. At least five generically different types of advanced storage technology are under study. Ideas for improved thermal systems include storage media, such as salts and paraffins, that would utilize latent heat rather than sensible heat. In addition to advanced batteries, compressed-air systems, flywheels, and superconducting magnets could be used for electric storage.

Today, storage may cost anywhere from $4 per kilowatt-hour for thermal storage in a water tank used in conjunction with a home solar system, to $50 per kilowatt-hour for lead-acid batteries. Pumped hydroelectric storage costs approximately $10 per kilowatt-hour of capacity, considerably less than batteries. Some analysts project that the annual storage of hot water in underground aquifers could cost as little as 5 cents per kilowatt-hour of storage capacity. Projections for untested systems are, of course, risky, but estimates for compressed-air systems, flywheels, and superconducting storage systems are in the range of $25 to $75 per kilowatt-hour. What people generally mean by a breakthrough into "cheap" storage is a cost on the order of cents per kilowatt-hour. Viewed as stored energy, coal and oil cost about 1 cent per kilowatt-hour.

There are a number of promising lines of research in storage technology, and programs being carried out now—largely by the Department of Energy—are building up the technical base that will be needed. Given the cost gap that needs to be spanned, it is clear that a sustained development effort is in order. But energy storage research is a conceptually rich field, and since it will be two decades or more before the long-term problems of solar energy must be faced, there are reasonable grounds for optimism.

For the near term, however, there are so many alternatives available that the lack of cheap storage technologies should not be an impediment to the growth of solar energy.—WILLIAM D. METZ