# Solar Cells Turn 30

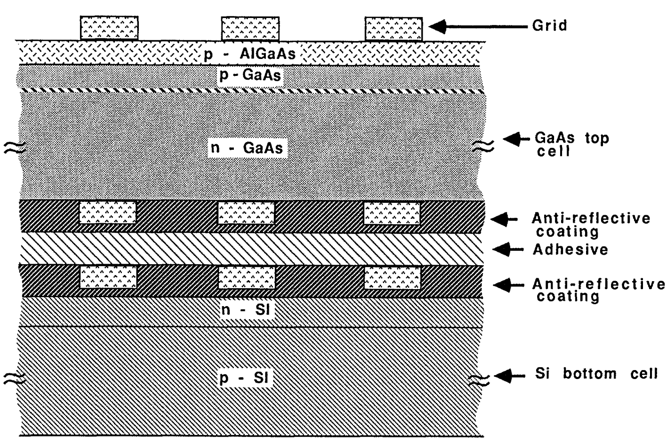
*Photovoltaics have passed an important milestone with the development of the first solar cell to surpass 30% efficiency in converting sunlight to electricity*

SOLAR CELLS HIT "the Big Three-Oh" this month—30% efficiency, that is. For the first time, researchers demonstrated a solar cell that converted more than 30% of the light striking it into electricity. Scientists from Sandia National Laboratories stacked two different solar cells—one made by Varian Associates Inc. of Palo Alto, California, and the other by Stanford University—into a double-decker arrangement whose efficiency reached 31%, a full 2% better than the previous best solar cell.

Solar researchers caution, however, that just as with a person's 30th birthday, the solar cell's "Three-Oh" is really more a psychological milestone than a sign that solar power has suddenly reached maturity. If anything, the complicated, expensive method used to reach 30% shows just how difficult it will be to bring solar power to the point where it can provide a significant portion of the country's electrical power.

For solar power to be an economically feasible alternative to other sources of utility-provided electricity, such as nuclear energy or fossil fuels, the cost of generating electricity from sunlight must be comparable to the costs of those other sources. The cost of solar power depends on two factors. The first is the efficiency of the solar cells—the percentage of the light energy striking the cells that is converted into electric energy. The higher the efficiency, the fewer solar cells are necessary to produce the same amount of energy, so it is important to make the efficiency as high as possible. The second factor is the cost to produce the cells and to put them into operation, which should be as low as possible. The overall price includes such things as the manufacturing costs of the modules in which the solar cells are placed, which can sometimes be quite complicated and expensive, as well as capital investment, including such things as land and plant construction costs—and repair and maintenance costs.

Unfortunately, the two factors work against each other. In general, the higher a cell's efficiency, the more expensive it is, and because of this trade-off, it may be just as cost-effective to use low-cost, low-efficiency cells as it is to use high-cost, high-efficiency ones.




**The stacked solar cell** *assembled at Sandia National Laboratories has a gallium arsenide top cell attached to a silicon bottom cell. The upper cell responds mostly to blue light, while the lower operates in the red portion of the spectrum.*

At this point, neither option is cheap enough for utilities to consider. Current solar cell systems can produce electricity at 30 to 40 cents per kilowatt-hour, and the Department of Energy estimates this must come down to 12 cents before utilities turn to solar energy for such specialized uses as peak-power units, and down to 6 cents before solar power comes into widespread use in the generation of electricity.

Dan Arvizu, supervisor of Sandia's Photovoltaic Cell Research Division, says one way to reach this goal is to develop the understanding to achieve very high efficiency solar cells and "let the brilliant minds in manufacturing make the tradeoffs to make it cost-effective." With this in mind, the DOE had set 30% efficiency in stacked solar cells as a short-term goal, which the Sandia group has now done, and 35 to 40% in the long run. To pass the 30% mark, the Sandia group used a specialized solar cell that is far removed from the low-cost, mass-produced cells that power electronic calculators.

First, the 0.317-square-centimeter cell is actually two solar cells placed one on top of the other. The purpose of such an arrangement is to convert as much of the light spectrum as possible to electricity since a single cell responds mostly to just one portion of the spectrum. (The common solar cells used on calculators, for instance, respond mostly to blue and ultraviolet and ignore much of the rest of the light striking them.) In the Sandia double cell, the top cell absorbs light mostly from the blue end of the spectrum while the bottom cell picks up light from the red end.

Second, the cell is designed for use with a lens that concentrates sunlight to several hundred times the brightness of the noontime sun. The 31% efficiency came at 350 to 500 suns, where 1 sun is 100 milliwatts per square centimeter of light intensity, or about the brightness of the sun at noon on a clear day. Using a lens, or concentrator, to collect sunlight from a large area and focus it on a small solar cell increases the efficiency of the cell (the Sandia cell is only 23% efficient under 1 sun), but there are trade-offs. There is a certain unavoidable loss of light in the lens, for example, which decreases the overall efficiency of the lens-cell system. Also, using a concentrator adds to the cost of the entire system since one must pay not only for the lens but also for a tracking system to keep the lens pointed at the sun. Although a solar cell responds to light from any direction as long as it strikes the face of the cell, a concentrator system works only when the lens is aimed at the source of the light.

Third, the Sandia group used the best solar cells available. Where the inexpensive cells used on calculators have efficiencies of 3% or less, and the high-cost cells being developed for powering space projects have efficiencies up to 20%, the top cell in the Sandia stack had an efficiency of 27.2% (under 350 suns). The bottom cell picked up an extra 3.8% of the light, to bring the total to 31%, but that 3.8% figure is misleading. The bottom cell, a single-crystal silicon cell developed by Stanford University researchers, is state-of-the-art but rated only 3.8% in the tests because only a small percentage of the incident light made it through the top cell to the bottom one. By itself, the Stanford cell has 26% efficiency at 150 suns.

The top cell, a single-crystal gallium arsenide cell made by Varian, is a story in itself. The California company is fast approaching a 30% efficiency in a single solar cell without stacking. In May, the company announced a gallium arsenide cell that hit 28.1% efficiency under 400 suns, and this summer Varian reached 29% by topping the cell with a special prism cover that allowed a bit more light to reach the cell. With these advances, gallium arsenide has moved ahead of silicon for the first time in providing the most efficient solar cells. The best single-crystal silicon cells have efficiencies of around 28%.

Sandia's solar cell sandwich is simple enough in concept—it consists basically of the two cells joined by an adhesive material. But putting together an efficient stacked solar cell involves more than just slapping two good single cells together, Arvizu says. The cells must be carefully matched to maximize their combined performance, and the most efficient single cells may not be the best in a given combination.

For instance, Sandia did not use Varian's 28.1% cell as the top cell in its stack because it had several special requirements that lowered the efficiency. For example, in order for light to pass through to the bottom cell, the top cell had metal grids on its bottom surface instead of the usual completely metallized surface, and the top cell was more lightly doped than usual (doping means lacing the material with certain impurities to improve its properties) so that more light would pass through it.

So what does hitting "Three-Oh" mean to the solar power effort? In practical terms, very little. "Demonstrating that these things can be done is important," Arvizu says, but he doubts multi-stack collector systems will reach the 12 cents per kilowatt-hour milestone first. A safer bet, he says, is thin-film solar cells that operate under one sun with lower efficiency but that are much cheaper than the high-efficiency cells. Robert Annan, DOE's director of photovoltaic research and development, agrees, noting that since it is the low-efficiency cells that industry is already making, it will be much cheaper in the short run to produce solar power with these cells. However, he says, "the high-efficiency stacked cells will be the ones that take us to 6 cents [per kilowatt-hour]."

■ Robert Pool

# A Bright Spot on the Solar Scene

Arco Solar Inc. recently announced what some are calling one of the biggest breakthroughs in the history of solar energy. The company, a unit of Atlantic Richfield Corp., has developed a thin-film solar cell with an 11.2% efficiency—much higher than existing cells of similar type. If the new solar cell lives up to its billing, it just might make collecting sunlight a commercially feasible alternative to smashing atoms or burning fossil fuels.

"It's a real landmark, the biggest news to break this year in solar cell research," said Jack Stone, director of solar electric research at the Solar Energy Research Institute (SERI), which worked with Arco Solar on the new cell. SERI, which is owned by the Department of Energy, is spending $4.2 million and Arco Solar is spending $4.8 million in a 3-year partnership to develop solar cells and panels.

The reason for the excitement is that Arco Solar and SERI have taken a giant step in an industry where baby steps are the norm. In the struggle to squeeze more electricity out of sunlight, it is considered a victory to raise the sunlight-to-electricity conversion ratio by a few tenths of a percent. Yet Arco Solar has, in one step, developed a solar cell whose working efficiency is a good three percentage points higher than the best the solar industry could offer just a few months ago.

The breakthrough came in the area of thin-film solar cells, a low-cost type of cell whose low efficiency is offset by the fact that it is relatively inexpensive to manufacture. (A thin-film cell, like it sounds, consists of a film of silicon or other photosensitive substance deposited on a base layer, as opposed to a single crystal, which is one solid piece of silicon or other material.) Solar-powered calculators, for example, use thin-film solar cells with sunlight-to-electricity conversion ratios of 3% or less. Although thin-film cells are much less efficient than single-crystal cells—the best of which now reach 28 to 29% efficiency—the fact that thin-film cells can be made cheaply makes them the favorite candidate to produce commercially competitive solar power for utilities.

The giant step in efficiency came from using a relatively new material for the cell. Most thin-film cells are made of silicon, and the best large silicon thin-film cells have efficiencies of just over 9%. (Smaller cells can have larger efficiencies because it is easier to make a small cell more uniform, but the industry judges cells for use in generating electric power on the basis of how efficient a 1-square-foot cell is.)

Arco Solar reached 11.2% efficiency in a 1-square-foot copper-indium-diselenide (CIS) cell. Charles Gay, senior vice president of manufacturing, research, and engineering at Arco Solar, said the breakthrough came from "a number of years of hammering away at a number of problems." As early as late 1985, he said, his lab had a small CIS cell with 12.5% efficiency, but scaling that up to a practical size took nearly 3 years.

The jump from 9 to 11.2% is significant by itself, but the CIS cell has another big plus. Silicon cells degrade when exposed to sunlight and quickly lose 10 to 20% of their efficiency, but the CIS cell seems to remain stable, according to Ken Zweibel at SERI. This means that the best available thin-film silicon cells can be expected to perform at 8% efficiency or less, as compared to a stable 11.2% for CIS.

The CIS solar cell has five layers. The substrate is topped with a layer of molybdenum that serves as an electrical conduction layer for the back of the cell. Then comes a 1-micrometer layer of copper-indium-diselenide ($CuInSe_2$) and a 0.03-micrometer film of cadmium sulfide (CdS). On top is a layer of zinc oxide (ZnO) that is transparent to sunlight, so that light can pass through to the CdS and $CuInSe_2$ layers, but that is electrically conductive to serve as the second electrical contact layer.

Once a plant is set up to manufacture CIS cells, the cells should cost about $100 a square meter to make, or about the cost of the existing commercial thin-film silicon cells with 7% efficiency. Ultimately, the goal is to bring the manufacturing costs down to $50 a square meter and improve the efficiency to 15%, at which point the Department of Energy estimates solar energy could be competitive with other forms of power.

For now, Gay said, Arco Solar will concentrate on turning a laboratory product into a commercial one. The company will need to start making large quantities to see what the actual cost is, and will provide the CIS cells to SERI and utility companies for testing, he said. "It takes a whole lot of work to bring this to market." ■ **R.P.**