PV FAQs

What's new in concentrating PV?

The concept of concentrating the sun's energy has been around since ancient Greece, when some historians believe that Archimedes used mirrors and the sun's energy to set attacking Roman ships on fire. Frankly, some people think concentrator technology hasn't come very far since then.

However, concentrating photovoltaics (CPV) has advanced considerably in the last few decades—not to mention the last handful of years.

How do concentrators work?

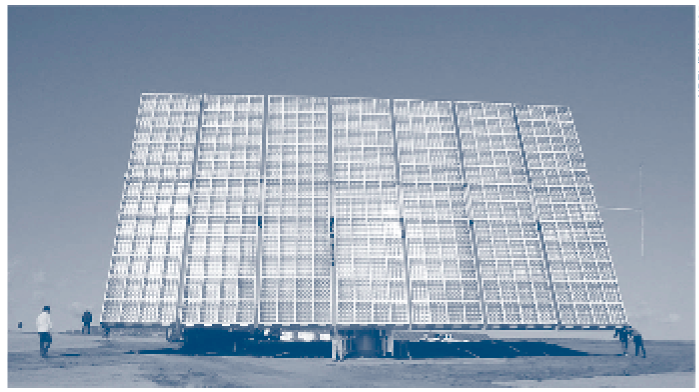
Much as magnifying glasses can concentrate sunlight and burn holes in leaves, concentrators use optics to concentrate sunlight onto a small area of solar cells. These photovoltaic (PV) cells convert the light into electricity—clean, homegrown, and pollution free—that we can use to run our appliances or light our homes.

Most concentrators follow the sun as it crosses the sky, either through single- or dual-axis tracking. This tracking capability allows concentrators to take advantage of as much daylight as possible from dawn until dusk. However, many permutations of CPV exist, as the photos throughout this FAQ show. Some CPV technologies use mirrors to reflect and concentrate all the sunlight they can capture onto small high-efficiency PV cells.

Gabriel Sala/PIX13744

Figure 1. Parabolic troughs, like those used in this Euclides-Thermie installation in Spain, concentrate sunlight onto a strip of high-efficiency solar cells positioned above the troughs.

Other CPV technologies use lenses to concentrate the sun's light. CPV technologies also differ in how strongly they concentrate sunlight, whether they concentrate light to a line or a point, the type of solar cell that they use, and whether the cells are actively or passively cooled.



NREL/PIX13735

NREL/PIX10748

Figure 2. Arizona's state-mandated portfolio standard gives concentrating PV a welcome boost. This Amonix installation for Arizona Public Service features dual-axis trackers and uses optical lenses to concentrate sunlight onto cells within each square.

Figure 3. These single-axis concentrating PV cells use curved optical lenses to focus the sun's light onto a strip of cells inside the module. The cells are undergoing testing at NREL's Outdoor Test Facility.

I heard about a CPV system that operates at 100 suns. What does "suns" mean?

One "sun" is the amount of energy you would sense if you held your hand out on a cloudless day—approximately 100 watts of solar energy per square foot, or 1,000 watts per square meter. When the light from 100 square centimeters is focused onto 1 square centimeter, the intensity of the light is about 100 suns. But if you shine more sunlight onto a cell, does the cell really produce that much more energy? Or is some energy "lost"? The answer is no, energy is not lost. If you shine 10 times more light

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onto a properly designed CPV cell, it produces more than 10 times the electricity; 100 times more light means more than 100 times the production—and so on. The correlation is greater than one-to-one, because conversion efficiency is higher under concentrated light.

What are the benefits of CPV?

The three primary benefits of CPV are: 1) high efficiency, 2) low system cost, and 3) low capital investment to facilitate rapid scale-up. Concentrating optics focus the light so that the semiconductor or solar cell is much smaller than for flat-plate systems. Because fewer solar cells are needed, the costlier, very high-efficiency solar cells can be used. Some current CPV technologies feature cells with efficiencies as high as 26%. Spectrolab's CPV cells have achieved 37.3% efficiency, and efforts are under way to integrate these into commercial systems. The reduced use of semiconductor material provides a pathway to lower cost, as expensive semiconductor material is replaced with inexpensive mirrors or lenses.

A recent Arizona Public Service study shows that CPV is competitive compared with some other PV technologies (see Figure 4). For every $1,000 that Arizona Public Service invested in CPV, an average of about 300 kilowatt-hours (kWh) is generated annually. This exceeds the number of kWh obtained each year from a similar investment in fixed flat-plate systems. However, the amount of energy from CPV is still less than the amount obtained each year from the single-axis tracked systems. Although this study shows that single-axis tracked flat-plate systems currently deliver the most electricity per dollar invested, flat-plate systems are mature compared with the CPV systems. In a few years, after the technology has moved further along its learning curve, the CPV systems may deliver the best value. After the technology has integrated today's high-efficiency CPV cells, a $1,000 investment could yield 450 kWh per year.

Another benefit of CPV technology is that it may be easily and economically scaled up as market demand increases, because of both materials availability and the comparatively low cost of building a CPV production facility. Table 1 compares the costs of building plants for various technologies. Based on their lower costs, CPV module plants should prove attractive to investors. In fact, manufacturing of CPV systems resembles automobile manufacture more than flat-plate PV manufacture.

Table 1. Cost to Build 100-Megawatt/Year Manufacturing Plant

Technology	Cost ($ Million)
Crystalline-silicon PV	150–300
Thin-film PV	150–300
Concentrating PV	30–50

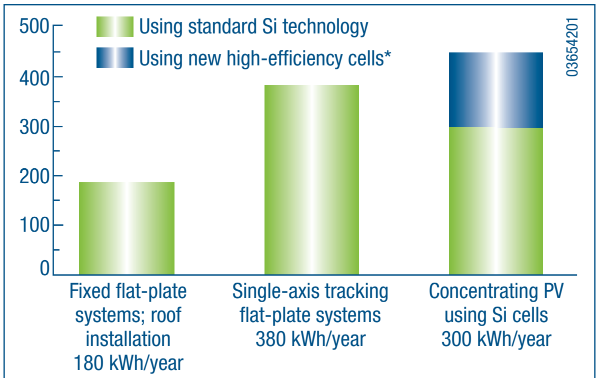
Concentrators only work in the desert, right?

It is true that deserts have the most sunlight available to use, and that CPV systems will first enter markets in the sunniest regions of the world. However, CPV can make sense in less sunny regions, especially where electricity costs are high.

The number of sizable CPV installations is limited, so we don't have a large database of CPV system costs. However, an early study by Richard Swanson of SunPower Corporation implies that CPV may be cost effective almost anywhere in the United States. In the study, Swanson compared the cost per kWh for a variety of CPV and flat-plate PV technologies. He found that for medium-sized utility plants in Boston—not exactly the desert Southwest—gallium-arsenide-based CPV dishes were more economical than flat-plate technologies.

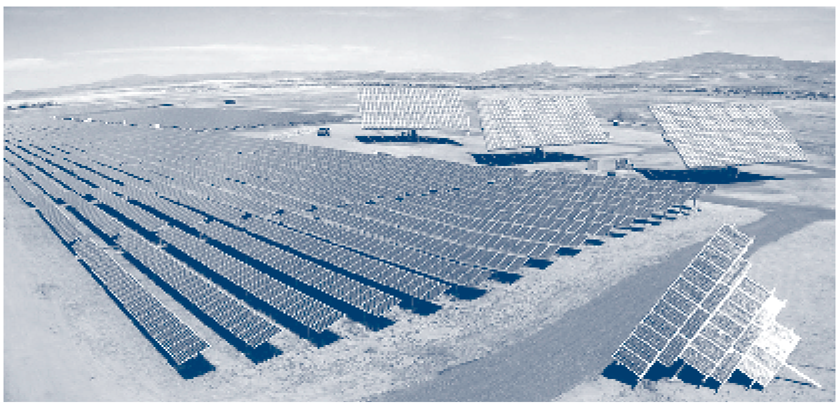
Why aren't concentrators on rooftops?

The answer to this question is tricky, because although CPV is almost always designed and intended for ground installations, innovative companies are breaking that rule. We'll discuss one of these rule-breakers in the innovations section; for now, let's address the reasons why we don't see traditional CPV installed on rooftops.



*Extrapolated assuming a fixed system cost when the higher-efficiency cells are put into the system.

Figure 4. Annual energy produced for $1,000 investment, based on large Arizona Public Service installations



Arizona Public Service/PIX13739

Figure 5. PV systems at the Arizona Public Service facility in Prescott, AZ, use a combination of technologies. The systems in the foreground are single-axis-tracking, flat-plate silicon systems. Shown in the upper right are three large (35-kW) Amonix CPV systems. The data in Figure 4 were obtained from systems such as these.

Except for the lowest-concentration designs, concentrator systems must track the sun in order to keep the light focused on the solar cell. A standard concentrator design mounts a large system on a pedestal, then pivots the system on the pedestal. It is difficult to adequately support such a pedestal on a rooftop, and most people would question the aesthetics of a high-profile system on their roof.

On the other hand, CPV is well suited for utility-scale installations because the concentrator systems: 1) tend to generate electricity when the utility needs it most to service air-conditioning loads, 2) can have high efficiencies if high-efficiency cells are used, and 3) can be made at lower cost when installed in large volumes.

Low-concentration CPV technologies—systems of less than 10 suns—are being developed for rooftops. Some of these systems don't have trackers and they look a lot like flat-plate PV. In fact, some low-concentration CPV is even being incorporated into existing flat-plate technology using clever optics.

What are the challenges facing CPV?

One important technical challenge for CPV is reliability. As with flat-plate PV and wind energy, CPV needs to be reliable so that utilities will trust the technology and buy into it. One of the key ways to ensure reliability is to develop codes and standards that CPV technology must reach to be certified. In 2001, IEEE qualification standards were completed for CPV; international standards are on the way.

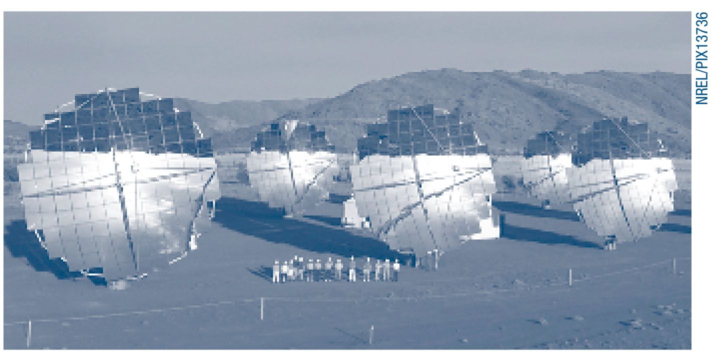


Figure 6. These 20-kW Solar Systems dishes dwarf visitors in Alice Springs, Australia. The concentrators use an array of mirrors to focus sunlight onto high-efficiency cells. Four supports hold the cells in front of the mirrors; the supports also supply cooling water and electrical connections.

Perhaps the biggest challenge facing the CPV industry has less to do with technological hurdles than with developing a market. Only two companies have penetrated the utility market with large-scale installations—one in Arizona (Figure 2) and one in central Australia (Figure 6). What do Arizona and Australia and have in common? True, they both have plenty of desert sunshine. But they also boast generous government support.

The State of Arizona has a mandated environmental portfolio standard requiring that 1.1% of retail energy has to be derived from renewable sources, and 60% of that must be from solar electric technologies. Arizona Public Service contracted with

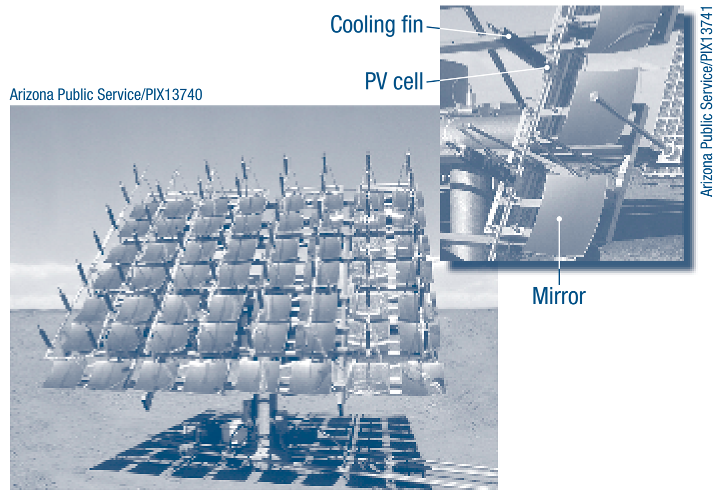


Figure 7. The MicroDish is made by Concentrating Technologies using Spectrolab solar cells. It is the world's first grid-tied high-concentration CPV system to use the latest high-efficiency cells. The dual-axis tracking modules use small mirrors to focus sunlight onto high-efficiency multijunction cells. Individual fins extend outward to cool each cell. This MicroDish is supplying electricity to the Arizona Public Service grid.

Amonix for 0.5 megawatts of installations because it believes that, for many locations, concentrating PV is a potentially low-cost energy source.

The Australian government provides significant funding for Solar Systems' projects in the outback. The installations provide electricity for communities that otherwise would have no electricity at all, or that would have to use diesel-fueled generators, which require cost-prohibitive diesel-fuel transportation.

Why has the market for CPV lagged?

Government support of CPV is important. Fossil fuels have benefited from government support for decades. Market incentives have enticed utilities to use wind energy. Some analysts even credit California's standard-offer contracts with kick-starting the success of wind energy in the 1980s.

As with fossil fuels and wind energy, CPV would also benefit from long-term, steady support of state and local organizations. As discussed above, Amonix and Arizona Public Service have already demonstrated this reality. The state's environmental portfolio standard has helped provide Amonix with an opportunity to introduce CPV to the Arizona utility market.

What technology advancements will help CPV grow?

Although support of CPV is crucial for market penetration, improved technology will also play an important role. The use of increasingly efficient PV cells already promises to decrease the cost of electricity generated by CPV.

The High-Performance PV Project at the National Renewable Energy Laboratory (NREL) seeks to develop and implement some of the technological innovations that will reduce the cost of energy from CPV. Specific goals include concentrator cells with 41% efficiency and CPV modules with 33% efficiency.

Under a High-Performance PV project subcontract, Spectrolab has been working to reach these goals. Multijunction cells made by Spectrolab and recently tested at NREL received an efficiency rating of 37.3%. Merely replacing the standard 25%-efficient silicon cells in a given system with these new higher-efficiency cells would increase energy production by about 50%. If cell cost does not change dramatically, using the higher-efficiency cells could lead to a 33% reduction in electricity costs. That will lead to a more competitive technology and a bigger piece of the market.

What innovative uses for CPV are coming?

Innovative placement of CPV holds promise in helping to grow the market. One idea is to place CPV in parking lots. Flat-plate PV is used atop carports; similarly, placing CPV in parking lots would create dual use of under-utilized land space.

Finally, remember the question addressed earlier, "Why aren't concentrators on rooftops?" Rooftop installation is currently becoming a practical goal for a new generation of CPV. For example, it may come as a surprise that Japan's largest PV manufacturer, Sharp, is developing a high-efficiency concentrator for rooftops (see Figure 8). Japan's densely packed population centers are filled with large apartment buildings that have limited roof space to serve a high density of people. CPV makes sense because, compared to flat-plate PV, concentrating PV can produce more energy in less space. This is important in a country where the cost of electricity is well over 20 cents per kWh.

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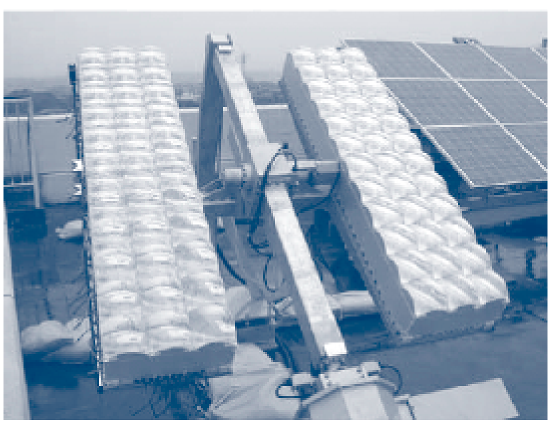

Araki et al./PIX13742

Figure 8. Daido Steel's Toyohashi 200-watt module is lightweight and uses high-efficiency multijunction cells—perfect for rooftop installation in population-dense places like Japan.

Beyond creative siting, new ways to use CPV may be on the horizon. The CPV industry has also explored the idea of combining CPV with hydrogen production for regenerative fuel cells.

Solar Systems has discovered that an electrolyzer heated by CPV gives an almost 40% thermal boost to hydrogen production from a solid-oxide electrolyzer. This finding opens up an unexplored and potentially important arena for CPV: hydrogen generation to fuel our nation's automobiles.

What's the bottom line for CPV?

Concentrating PV offers many benefits over other ways of producing electricity, but, like wind energy in its early days, it also faces many challenges. During the last several years, CPV has heralded some important advances, including high-efficiency cells, module advancements, and IEEE qualification standards. With continued focus on reliability, technological improvements, and market penetration, look for utilities to consider CPV as a serious energy alternative. After all, concentrating the sun's energy is hardly a new idea.

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For more details about CPV, please contact Robert McConnell or Martha Symko-Davies at NREL: 303-275-3000.

For more information on PV, please read the rest of the PV FAQs in this series. You can order hard copies of the FAQs from the National Center for Photovoltaics, or visit our Web site at *www.nrel.gov/ncpv*.

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