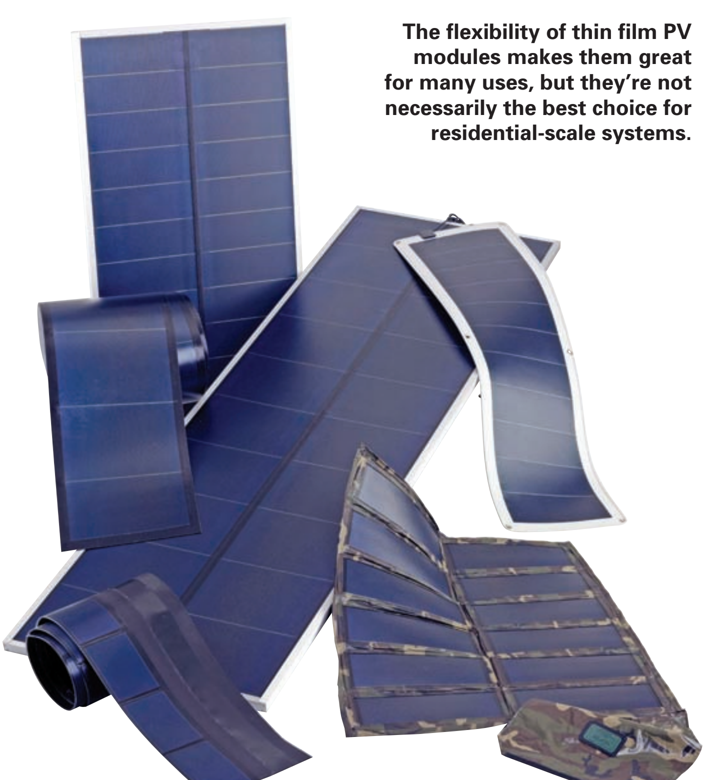
Solar-Electric Options:

Crystalline vs. Thin-Film

by Erika Weliczko

Options for residential solar-electric modules used to be nearly as limited as the choices Henry Ford offered when his Model Ts first rolled off the line. But times have changed, and so have the choices in PV technology. Now, besides conventional aluminum-framed and glass-topped single- or multicrystalline PV, consumers can choose from thin-film PV in frames or building-integrated products like metal roof laminates.

But what's best for your situation depends on a variety of factors, including budget, space limitations, and climate. Here's a rundown of the choices, and how to find the best technology to suit your needs.



The flexibility of thin film PV modules makes them great for many uses, but they're not necessarily the best choice for residential-scale systems.

Courtesy www.nrel.gov

Two Technologies

If you were to place a crystalline module beside a thin-film module, some differences will be more apparent than others. The first distinction is appearance. Single-crystal PV modules have distinct, dark-colored cells that are either rectangular or octagonal in shape; multicrystalline modules have some sparkle to the cells, and are usually rectangular. In each, the electrical connections are evident as a regular pattern of parallel, silver lines called traces.

"Thin-film" is used somewhat as a catch-all phrase, since it refers to a variety of module compositions, including amorphous silicon (a-Si), cadmium telluride (CdTe), and copper indium gallium diselenide (CIGS). One of the main advantages to amorphous silicon is that it can be directly deposited on glass or even plastic, allowing it to be manufactured in long, continuous rolls, or incorporated onto a flexible substrate, such as laminates, shingles, and roofing tiles—even backpacks. The appearance of amorphous silicon also tends to be more uniform. Because of the uniform color, thin-film products appeal to those with a major concern for aesthetics—architects, designers, and end users—for streamlined building-integrated applications.

But where the differences between the two module types really show up is in their sunlight-to-electricity conversion efficiencies and power densities. Crystalline modules require less space than thin-film modules for the same amount of power—thin-film is less efficient in the conversion of sunlight to electricity.

Single- and multicrystalline modules have typical conversion efficiencies between 12% and 17%. But thin-film technologies can have half that, ranging from 6% to 8%. Thin-film modules take up about twice as much space to generate an equivalent amount of energy compared to crystalline modules.

Sizing Systems

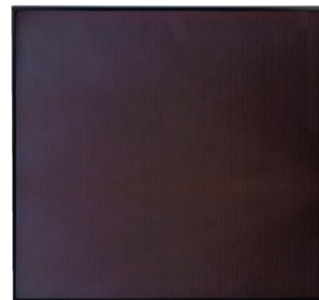
Let's take a look at how this difference influences PV system sizing. For a utility-interactive PV system, a typical crystalline module would be 170 to 220 W (STC), have an efficiency between 12% and 17%, and measure approximately 3 by 5 feet. An amorphous thin-film module might deliver between 60 and 70 W (STC) with an efficiency between 6% and 8%, and measure about 3 by 3 feet.

Besides power density, there are two key differences in performance between crystalline and thin-film technologies. The first is impact of cell temperature on power production. The second is initial module power stabilization.

All PV modules experience a reduction in power with increasing cell temperature. For example, at 100°F, our sample crystalline module will produce approximately 6% less power than its STC rating. This effect is less pronounced for thin-film PV technologies—our example a-Si thin-film module would produce only 2% less power. While you can reduce cell temperature by allowing adequate air flow around any module, PV cells sitting out in the sun will still get hot—so thin-film a-Si modules might be a good choice for warm climates, especially if there's plenty of room for the larger array.

The Sharp multicrystalline module (right) is 14 sq. ft. and rated at 170 W, over 12 W per sq. ft.

The Kaneka a-Si module (below) is about 10.2 sq. ft. and rated at 60 W, under 6 W per sq. ft.



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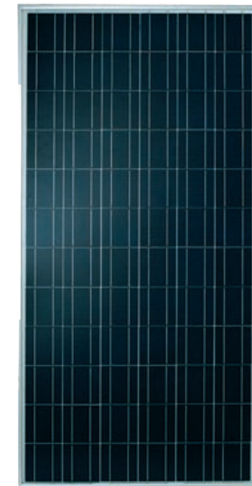


Courtesy www.solar.sharpusa.com

Crystalline vs. Thin-Film PV Technologies

Module Characteristics	Sharp Crystalline	Kaneka a-Si
STC power (W)	170	60
PTC power (W)	150	56
Dimensions (in.)	32.5 x 62.0	37.8 x 39.0
Module efficiency	13.1%	6.3%
Power density (W per sq. ft.)	12.13	5.87
Open circuit voltage (Voc)	43.2	91.8
Operating voltage (Vmp)	34.8	67
Number of modules in series at -25°F for under 600 VDC	11	5
Operating current (Imp)	4.9	0.9
Temperature coefficient of voltage (per °C)	-144 mV	-0.31%
Temperature coefficient of power (% per °C)	-0.49%	-0.19%
Cost per module	$1,029	$339
Cost per watt	$6.05	$5.65
Color	Dark blue	Maroon
Warranty (yrs. @ % of rated power)	10 @ 90%, 25 @ 80%	25 @ 80%

3 KW System Characteristics

Array STC power (W)	3,060	3,120
Number of modules	18	52
Area required (sq. ft.)	259	550
Mounting rail length (ft.)	102	345
Module electrical arrangement	2 strings of 9 modules	13 strings of 4 modules
Module physical arrangement	2 rows of 9, portrait	4 rows of 13, landscape
Array Vmp	313.20	268.00
Array Voc at -20°F	458.65	428.56
Array Vmp at 100°F	296.61	257.37
Est. retail equipment cost, all equipment & materials	$24,500	$31,000
Est. system installation cost, complete	$3,400	$4,600

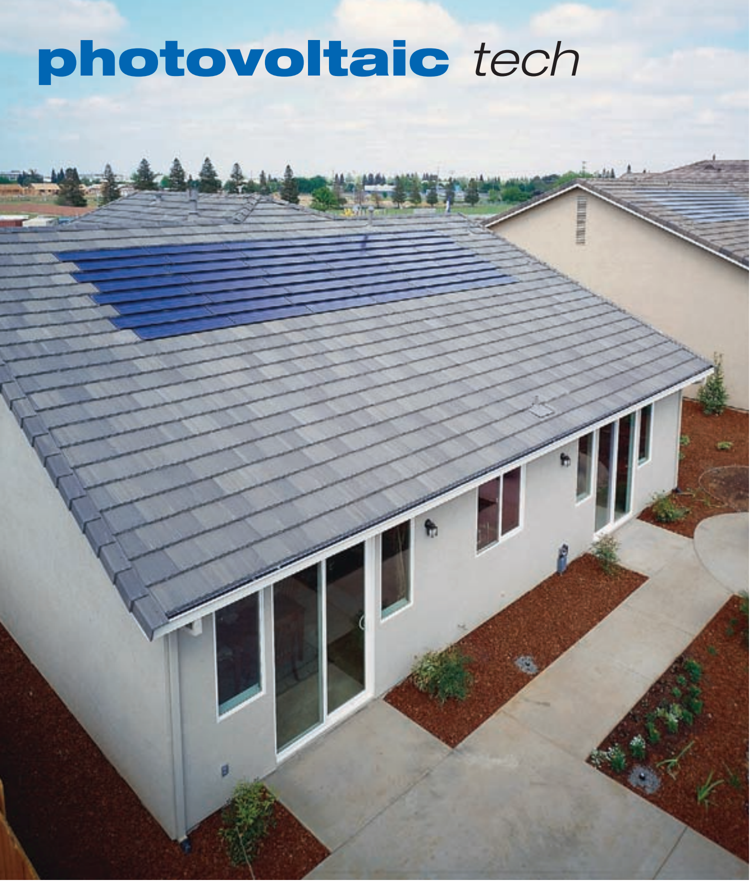
Amorphous silicon modules take 6 to 12 months to reach their stable, rated output, whereas crystalline modules stabilize right away. So a-Si modules will show 20% to 25% higher-than-rated production at first. While that sounds like a bonus, this initial additional output must be considered in system design (for selecting wire sizes, charge controllers, and inverters). For example, if the final design indicates a 15 A circuit, the initial extra output might require accommodating 20 A. After this stabilization, thin-film modules degrade at similar rates to crystalline, about 0.5% to 1.0% per year.

Some thin-film technologies provide better shade tolerance and low-light performance than crystalline modules. For example, Uni-Solar products are flexible and made with triple junction a-Si cells. The flexibility allows the use of bypass diodes across each cell within the module (not just within the module junction box), allowing current to flow around any shaded cell. And each "sub-cell" of the multi-junction cell can capture different light wavelengths, resulting in higher power production in cloudy weather and diffuse light. Other thin-film modules (without bypass diodes on every cell) have better shade tolerance than crystalline modules due to cell shape. Many thin-film cells are as long as the module itself, so shading an entire cell is more difficult than the traditional 5- or 6-inch square or round crystalline PV cell.

Other Considerations

When selecting an inverter, the voltage extremes of the array should be within the maximums of the inverter. Most thin-film modules have high voltages and low current. To keep voltages of batteryless systems below 600 VDC to meet *National Electrical Code* requirements, a higher voltage means fewer modules in series. Some inverters have optimal voltage ranges that span as little as 150 VDC, making it challenging to design arrays with thin-film modules that have open-circuit voltages approaching 100 VDC.

Battery charging PV systems have different voltage requirements. Historically, nominal PV array voltage would



Courtesy www.nrel.gov

Building-integrated PV products, like these roof tiles, can be made with crystalline PV cells, for an aesthetic look that requires less roof space than thin-film products.

have to match nominal battery voltage. However, with the advent of step-down charge controllers, up to three 24 V nominal modules in series can be used in some climates to charge a 12, 24, or 48 V battery bank. Using the same step-down MPPT charge controller, one high-voltage, thin-film module can be paralleled with its neighbors. Battery-charging systems with thin-film arrays will almost always require an MPPT controller with step-down functionality.

Comparing Costs

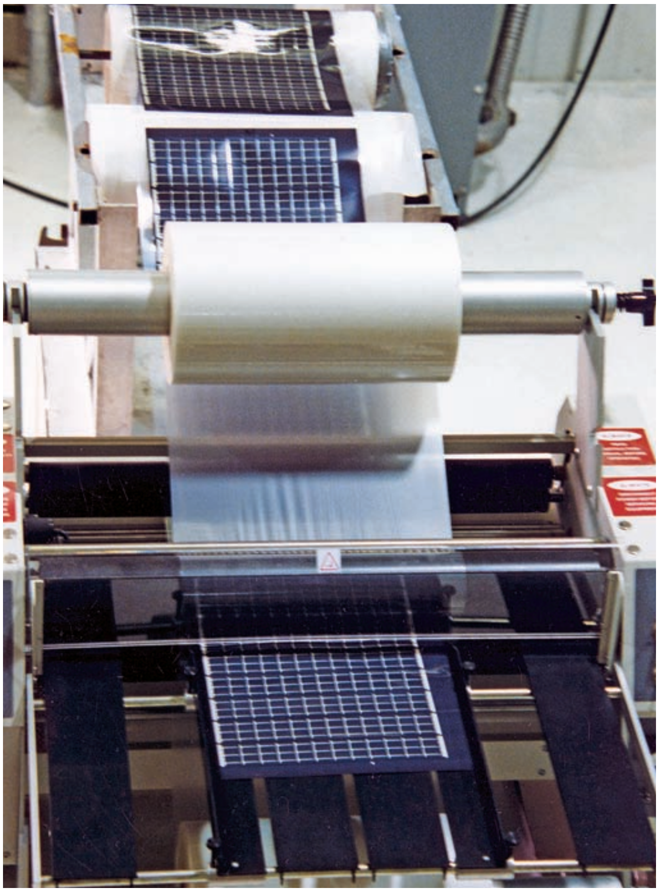
While the use of less material and energy during the manufacturing of thin-film modules creates a product that is less expensive per watt, the additional hardware and equipment costs usually increase the overall installation costs. As a result of the physical and electrical differences, California's Sacramento Municipal Utility District estimated that amorphous silicon modules needed to be $0.50 to $0.80 per watt cheaper than crystalline modules in order to be competitive.

To help get a handle on the differences between crystalline and thin-film, let's compare two 3 KW nominal systems (see comparison table). Assume that both are grid-interactive, batteryless systems with modules mounted on a roof in a rectangular arrangement using top-clamping racks. The racks support the modules, with two rails underneath each row, and four clamps secure each module to its rails.

Besides the basic equipment differences, installation differences emerge as well. If the crystalline modules use 102 feet of rail, this means locating and installing 40 mounting feet and lag bolts on the roof (assuming attachment points are installed every 32 inches). The 345 feet of rail required for the thin-film array would require triple that—129 attachment points. Additionally, since there are nearly three times the number of modules, installation of the modules and the clamps between them might take two to three times as long,

PV Technology & Efficiency

Thin-film modules don't necessarily need glass. Flexible plastic substrates and laminated coatings can keep them light and flexible—perfect for low-power, portable needs.



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Crystalline & Thin-Film Advantages & Disadvantages

Advantages

Crystalline Silicon	a-Si Thin-Film
Highest power per area	Output less affected by temperature
Requires less racking & support material	Less manufacturing materials used
Fewer modules means lower shipping costs	Lower cost per watt
Large number of module choices	Good aesthetics for building-integrated applications
Greatest inverter flexibility	Less embodied energy (faster energy payback)
	Non-glass substrates possible
	More shade tolerant

Disadvantages

Crystalline Silicon	a-Si Thin-Film
Higher cost per watt	Lower power per area
High temperatures affect output more	Takes months to stabilize output
Low shade tolerance	Twice as much rack material required
Individual cell visibility	More modules mean higher shipping costs
	Lower series-string capacity
	Less suitable for battery charging
	Requires more combiner boxes
	Limited inverter flexibility
	Fewer module manufacturer choices

meaning higher installation costs. With a greater number of series strings, the conduit, wire, and additional labor necessary to get from the array to the combiner boxes is an expense that is not necessary for the crystalline array. The higher initial output of the thin-film array needs to be accounted for, which may translate into having to use a larger wire gauge and increased wire expense.

When considering the additional equipment, shipping, and labor next to the reduced module price, choosing the thin-film array increases costs by as much as $1.50 to $2.50 per watt. Is it worth it? It depends. Given site specifics like temperature and cloud cover, will the a-Si modules be 10% to 20% more productive? Thin-film manufacturers will say, "Of course!" And testing conducted in warm and sunny climates, as well as cooler and cloudier, has shown that a-Si modules typically produce slightly more KWH per peak KW capacity. The "Advantages & Disadvantages" table will help you compare and contrast the key features of each, so you can choose the best technology for your application.

Payback

As a result of using far less materials, the embodied energy of thin-film products is significantly less than crystalline products. The National Renewable Energy Laboratory reports that the energy payback time for thin-film PV technologies is about one-half that of crystalline modules. A thin-film module creates enough electricity in operation to offset its embodied energy within 1.5 years compared to within 3 years for crystalline modules (see "PV Energy Payback" article in this issue).

Access

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"Performance and Reliability of a 1-KW Amorphous Silicon Photovoltaic Roofing System," NREL • www.nrel.gov/docs/fy05osti/36583.pdf

Thin-Film Manufacturers:

Global Solar • www.globalsolar.com
Kaneka • www.kaneka.com
Schott Solar • www.schott.com/solar
SunPower • www.sunpowercorp.com
UniSolar • www.uni-solar.com

Crystalline Module Manufacturers:

Advent Solar • www.adventsolar.com
BP Solar • www.bpsolar.com
Canadian Solar Inc. • www.csisolar.com
Day4Energy • www.day4energy.com
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