

A Practical Guide to PV Efficiency

At the end of June 2016, the world record for efficiency of rooftop solar modules was broken again: the US-based PV manufacturing company SunPower achieved an efficiency of 24.1% for a monocrystalline silicon-based PV panel ([Newsroom, 2016](#)), over 2% higher than the previous record. This news came shortly after the announcement earlier in the month of Hanwha Q CELLS breaking the efficiency record of polycrystalline modules with 19.5% efficiency ([PR Newswire, 2016](#)), and the German research centre ZSW setting a new record for thin-film technology, with a small research cell testing at 22.6% efficiency ([ZSW, 2016](#)).

But what does PV efficiency mean for people working in the solar industry, where typical PV efficiencies are not nearly as impressive? How far removed are these records from the real world? What module efficiency is ideal for a given solar system?

Efficiency records

Firstly, we should differentiate between the various PV technologies available and their efficiency records. The 24.1% SunPower record was based on monocrystalline silicon technology, the Hanwha Q CELLS utilised polycrystalline silicon technology, and ZSW efficiencies were achieved with CIGS (copper indium gallium diselenide) thin-film technology.

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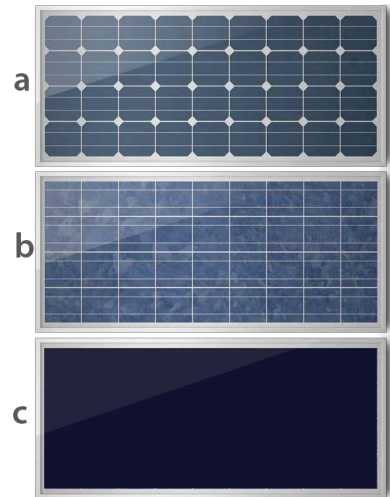


Figure 1: a) Monocrystalline silicon, b) polycrystalline silicon, and c) thin-film PV modules.

Of these three mainstream PV technologies ([Figure 1](#)), monocrystalline silicon is typically the most expensive but is capable of achieving the highest energy conversion efficiency, while thin-film is the least expensive with the lowest efficiency, but new technologies are moving towards commercialisation.

The separate technology categories for efficiency records are essential due to the different physical limitations. The current record for any PV energy conversion technology is 46% ([Fraunhofer, 2014](#)) ([Figure 2](#)). However, the circumstances required to obtain this number, specifically by incorporation of four junctions or ‘sub-cells’, and a sunlight concentration of 508 suns, provides a good argument for distinguishing between technologies!

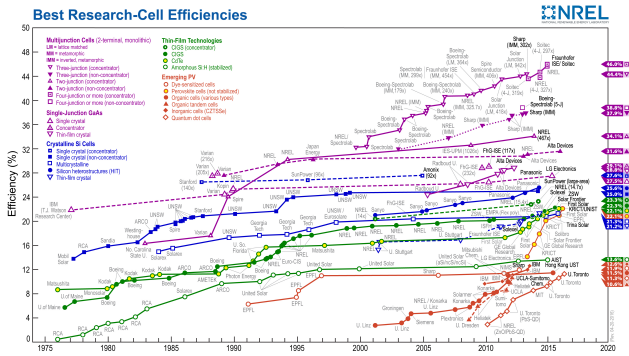


Figure 2: PV research cell record efficiency chart. This plot is courtesy of the National Renewable Energy Laboratory, Golden, CO (Click to view larger image) (Source: NREL).

Another way to tell the relevance of PV efficiencies in the commercial PV sphere is the method by which the cell or module was created. Most reported records concern a prototype PV device constructed using laboratory-grade materials and techniques and as such will naturally have superior performance to an equivalent mass-produced commercial device.

For example, SunPower's 24.1% efficient module was based on its X-Series module design, but assembled from 25% efficient laboratory cells. This is in contrast to their most efficient of the commercially available X-Series modules, the X22-360, which is currently rated at 22.16% efficiency using commercially produced cells instead. The X22-360 is currently the highest efficiency PV panel on the commercial market; most silicon solar panels are between 13 and 18% efficient.

The meaning of efficiency

A PV module specification sheet usually contains a module efficiency value. We know these numbers are an indication of performance, but what exactly do they refer to?

The efficiency of a PV module is simply a ratio of two numbers: the solar power that is incident on the panel under STC conditions (that is, the Standard Test Conditions with an irradiance of 1000 watts per square metre, a cell temperature of 25°C, and an air mass of 1.5, which determines what wavelengths of light are present) divided by the module's measured power output under the same conditions. PV module efficiency is denoted by the symbol 'η'.

$$\text{Efficiency } (\eta) = \frac{\text{Power available (as solar radiation)}}{\text{Power output (as electricity)}}$$

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If a solar module could convert energy perfectly, i.e. 100% efficiency, the power output would be the same as the power available. This is not possible due to several energy loss factors, some of which are illustrated in Figure 3.

- Solar energy being reflected by the glass cover
- Shading from metal conductors which are placed on top of cells to collect the electrical current generated.
- Not all of the solar energy converts to electricity via the photovoltaic effect – some wavelengths of light have excess power and some do not have enough to produce electricity.
- As electricity travels through the cells and cell interconnections, it encounters electrical resistance resulting in heat loss.

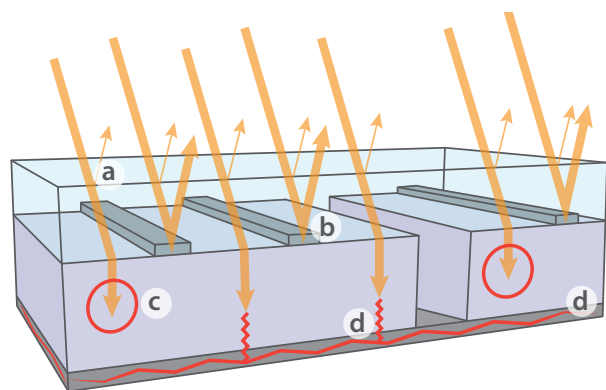


Figure 3: Sources of energy loss in a solar panel.

The efficiency of the module will always be less than the efficiency of the PV cell. The PV modules incur losses caused by reflection of light off the glass, shading of the cells from the connection bars, and the increased electrical resistance from the module's interconnections. The solar cells are not exposed to these losses.

The module efficiency does have a practical importance in relation to the PV design system or installation : this number determines the power output available from the module as a whole.

Efficiency implication in module selection

So how important is efficiency in selecting a PV module? The solar market over the past 5+ years has shown that the price of the PV module was the most important factor, and not the module efficiency.

The rated power of a solar module already takes into account its efficiency, so a module with reduced efficiency is typically characterised by an increased physical size relative to a module of the same rated power but higher efficiency (Figure 4a). Alternatively, if two modules are the same physical size, the lower module efficiency will be associated with a lower rated power (Figure 4b). This is often the case when a manufacturer offers a single panel brand or model for a range of power ratings.

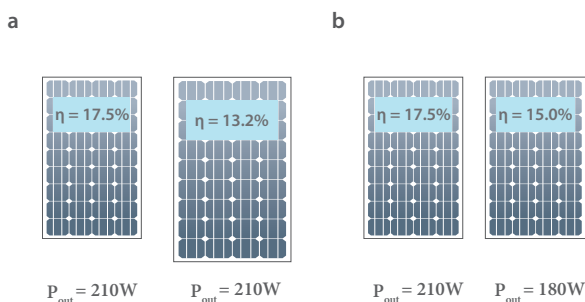


Figure 4: a) Effect of efficiency on module size at identical power output. b) Effect of efficiency on power output at identical physical size.

In some cases, such as satellite applications or a client having limited installation space, both the available area for the array and the required power output will have been specified: in such situations, the process of choosing a solar panel type may be assisted by a rough efficiency calculation. By dividing the specified rated power by the available area multiplied by 1000W/m², a minimum efficiency figure can be obtained, immediately narrowing down the module choice.

Keep in mind, however, that the efficiency of

$$\text{Minimum module efficiency} \cong \frac{\text{Specified rated power of the array (W)}}{\text{Available installation area (m}^2\text{)} \times 1000 \text{ W/m}^2}$$

modules will have to be greater than the calculated value to account for inter-module spacing and any edge zones required.

In most PV systems, however, the driving design principle behind module selection will be system economics. PV modules at the wholesale level are priced by a dollar per watt (\$/W) value, and the module's price is the dollar per watt value multiplied by the module's rated output. This means that higher efficiency modules will cost more.

The choice of a suitable solar module may be made on the basis of the project circumstances. For example, matching the system output to the specified installation area dimensions, or choosing a rated power that multiplies neatly to achieve a desired array power rating.

Modules with higher efficiency offer economic advantages for commercial and utility scale projects where the value of the project requires maximum power production for the system installed.

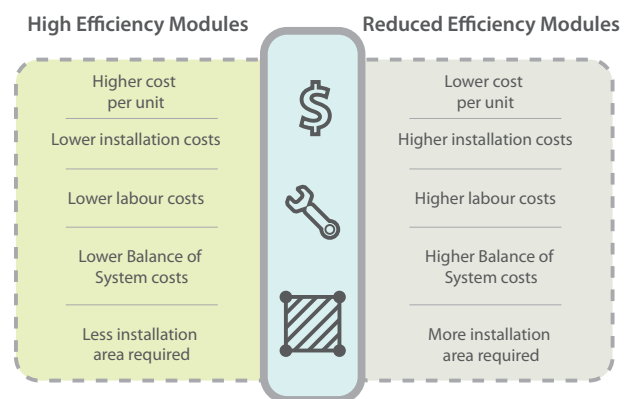


Figure 5: The above image summarises the cost differences that may apply when choosing high efficiency modules over reduced efficiency modules for a given installed capacity. Naturally these estimates are general in nature and are not specific to any module technology.

PV Efficiency implication for the Solar Industry

While the value of PV module efficiency is not obvious as part of the residential PV market, its importance is significant to commercial to utility scale applications. As larger scale projects are installed across Australia, the breakthrough in efficiency records for various PV technologies will provide project developers and system designers



with more options and flexibility to deliver large scale projects at reduced costs.

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