Future PV power plants

Utility solar | Recent years have seen huge decreases in the cost of electricity from utility PV arrays. However, with PV's grid parity battle not yet entirely won, competition to drive out further costs is still fierce. Ben Willis looks at some of the technological evolutions that will shape the next generation of PV power plants

Earlier this year the leading solar research institute Fraunhofer ISE completed a study for German think-tank Agora Energiewende documenting the past and projected fall in the cost of solar-generated electricity. From PV's first space-based applications in the 1950s to the current generation of large-scale power plants, the study said the progress made by a once-marginal power source had caught many people by surprise, with costs falling much faster than expected.

In Germany, for example, the study recorded a fall from €0.40 (US$0.44)/kWh in 2005 to €$0.09/kWh in 2014 in the cost of power from large-scale PV installations. Although figures such as these already make PV a low-cost renewable energy technology – the lowest in some parts of the world – the study predicted it had the potential to go much further, falling in Europe to between €0.04 and €0.06 per kWh by 2025 and to as low as €0.02 to 0.04 by 2050 based on conservative estimates. Indeed such levels are already being reached in some sunnier regions, with US firm First Solar recently announcing a PPA price for its 100MW Playa Solar 2 project in Nevada of US$0.0387 per kWh.

Even for those responsible for the growth in utility-scale solar, the cost story is still one of some wonder. Matt Campbell, senior director of power plant products at SunPower, remembers how even as recently as 2008, PV's economic viability compared to its nearest rival, concentrating solar power (CSP), was still in the balance. "At the time the conventional wisdom was that CSP was the technology of choice for utility-scale solar and PV was for distributed solar, and there were a lot of people sceptical about the ability to reduce the cost of PV," Campbell says.

But then firms including SunPower and First Solar took a leap of faith, signing power purchase agreements (PPAs) for such mega-projects as the 250MW California Valley Solar Ranch and the 550MW Topaz solar farm. "We bet on the future and got these big PPAs, and that was the kick-off of what I would call the utility-scale solar age," Campbell says. "The market in '07 was let's say 12 to 14 cents. And today you see people in the US signing PPAs for less than five cents per kilowatt-hour. So you've got almost a two-thirds reduction in just seven years. It's remarkable."

The question now is how far this can go. As the Fraunhofer report highlighted, while some have pointed to PV's success in bringing down cost as evidence of a dawning "solar age", the flip side to that coin is that the price declines the industry has achieved in a short space of time could slow down, prompting a sudden bursting of the "solar bubble".

One of the biggest risks for the industry, one that could give some credence to this latter view, is the threat of regulatory or financial disruption. In many markets, PV is still reliant on support either through direct subsidies, as in many European markets, or fiscal incentives, such as the investment tax credit in the USA. As PV becomes increasingly competitive, the risk of political support for a technology that has begun standing on its own two feet being withdrawn also grows. This has already happened in countries such as Spain and Germany, with serious consequences for those markets.

Ultimately preventing this happening is only marginally within the industry's control. Where the solar sector does have more control over its own destiny, however, is on the technology side, and here there would appear to be plenty more room for driving down cost.

According to Fraunhofer's analysis, the cost of a PV system, a key component of the levelised cost of electricity (LCOE) metric used to compare the cost of power from different sources, still has some way to go. Based on various different scenarios and assumptions around market development and technological learning rates, the study forecasts system costs falling from €935-1,055 per watt peak in 2014 to anywhere between €280-610/Wp in 2050.

Credit: First Solar

SunPower's Matt Campbell says projects like California Valley Solar Ranch kick-started the "utility-scale solar age".

Campbell agrees there is still plenty of headroom for driving out cost. But he highlights the fact that in the seven years or so of the "utility-scale solar age", the industry has already largely achieved most of the easy wins on the technology side. Most of the cost reductions to come he believes will be achieved through methodical, incremental improvements to many individual details rather than some single breakthrough piece of new technology.

Nevertheless, he has high hopes of what the industry can still achieve. "I've never been more excited about our ability to bring new innovation to the power plants," he says. "We've already done the low-hanging fruit. We did a lot of things that were easy and they had a huge impact; now it's a little bit harder. But when I look at our pipeline for next-generation products, there's going to be a lot of things that will make an impact."

This article looks at some of the key elements of a PV power plant and canvases opinion on where the biggest hopes for innovation lie in the next-generation of solar power plants.

Cells and modules

The module is the engine of a PV power plant and reductions in module costs has played a large part in the driving down of PV system costs. In terms of future module price developments, the Fraunhofer study conservatively predicts that the so-called "experience curve" – the rate at which manufacturers collectively drive down module average selling price (ASP) in proportion to the amount of experience and therefore innovation gained through producing a product over time – will continue, but slow and not return to historical rates of around 20.9% until 2050.

The two key drivers of continued cost reductions in modules will be improved efficiencies in both performance and material usage. Although thin-film PV has two notable players – First Solar with its CdTe technology and Solar Frontier with its CIS variant – crystalline silicon-based cell technology is expected to dominate for the foreseeable due to its relatively low cost and potential for efficiency improvements.

"Thin-film was quite interesting in the times when silicon was getting expensive during the feedstock crisis. But nowadays, crystalline silicon is so cheap and there's still such high potential in there," says Radovan Kopecek, co-founder of the ISC Konstanz research institute in Germany and head of its advanced solar cells department.

Kopecek foresees an ongoing transition to passivated emitter rear cell (PERC) technology as a new industry standard in crystalline silicon PV, a process that is already well underway among many manufacturers attracted by the higher yields offered by PERC cells. After PERC, he expects its near cousin, PERT (passivated emitter rear totally diffused) technology to take off, with the likes of Belgium's imec research centre having achieved a 22.5% conversion efficiency in an n-type PERT cell.

One trend that has come to the fore in the past few months that many are backing as a sign of things to come is the growing prevalence of bifacial modules. The jury is still out on what benefits the ability of bifacial technology to absorb light on both front and rear sides will offer in yield and therefore cost terms. But the matter could soon be settled when a 2.5MWp plant in Chile, La Hormiga, is completed later this year.

Credit: MegaCell

New cell technology could offer a fresh round of efficiency gains for modules.

This project is being touted as the world's largest bifacial system. It incorporates glass-glass modules containing bifacial 'BISoN' cells from Italian firm MegaCell, and claims to offer an LCOE of less than US$59/MWh per year. Kopecek believes the installation will settle the question over the benefits of bifaciality once ad for all.

"I think it will become a mainstream technology," Kopecek says, "and not because it's a cool technology but because people are going anyhow to bifacial cells and glass-glass modules. So you don't have to implement a new technology into your modules in future, but you can just use it on top."

System design

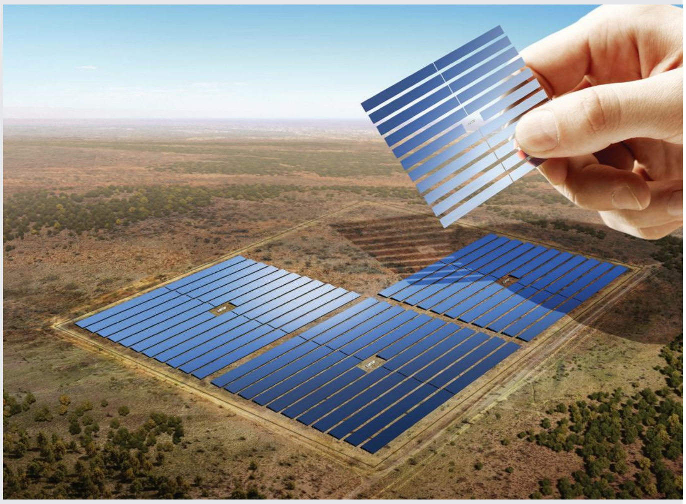
One of the key developments in the evolution of utility-scale PV plants has been the shift to modular design and construction that breaks plants down into a series of smaller, standardised units. SunPower's Oasis product is one example of this, a 1.5MW power block in which all the components are designed to function as a single system. As many of these individual building blocks as are needed can be deployed to make up a larger overall plant.

Campbell says the introduction of the Oasis approach has allowed SunPower to reduce its balance of system costs by more than half. "Its modular, integrated design ensures fast installation practically anywhere, reducing time to market," Campbell says. "At the recently completed 579MW Solar Star Projects, for example, we were installing up to 5MW per day."

Another prominent exponent of the power block concept is Germany's Belectric, which now offers its '3.0MegaWattBlock' as the standard building block of plants it builds. According to the company's UK managing director, Duncan Bott, the modular approach is one that the industry should now follow as standard.

"The PV industry needs to stop designing solar farms," he says. "We should just have a block – would you like a 1MW, 2MW or 3MW block sir? And then it becomes a modular approach; you don't need a million designs on every single piece."

Bott believes further developments around the power block concept are more than likely. In the past two years he says Belectric has been able to progress from a 2MW to 3MW block design largely as a result of collaboration with GE, whose 1500V inverter has been central to the concept's development.



Credit: Belectric

Belectric's 3.0MegaWattBlock concept is the basis of its modular approach to system design.

"GE developed that inverter, and that has enabled us to evolve from a 2MW block to a 3MW block. So therefore the cost of inverter by a per-MWp ratio has dropped, just because they have built a bigger and better design," Bott explains. "So will our 3MW block evolve? I would be tempted to say yes it will. How much to? That will depend on our inverter suppliers. But give us another year and I wouldn't be at all surprised if there's a 4MW block."

Inverters

If the module is the engine of the PV power plant, then the inverter is the brain. The biggest development here has been the 1500V model, which aside from such developments as Belectric's 3MW power block has brought with it a multitude of other benefits, including greater power densities and fewer AC connections, all of which mean cost savings in balance of system components such as transformers and wiring, and savings on labour.

Mahesh Morjaria, vice president of product management at First Solar, believes that just as the industry has largely moved from 600 to 1,000V plants in the past few years, a wholesale shift to 1,500V will be next. "The whole industry will move towards that for purely economic reasons," he says. "And we see in the industry there are more suppliers who are coming up with modules that are 1,500V and inverters that are 1,500V."

But he sees 1,500V as "just the next evolutionary step" for the industry, with even higher voltage ratings possible: "This will be dependent on a few other factors as well: usually it's pushing the standards to accommodate that and pushing the suppliers to have components that are capable of higher voltage levels. But I would not be surprised if we saw power plants at higher voltages as we develop the technologies to accommodate them."

Campbell however sees the move to 1,500V as less straightforward than the shift from 600V to 1,000. "We are pushing up against the voltage ceiling of commercially available IGBTs [switches] and BOS component technologies. Maintaining reliability will be the challenge as newer, higher voltage inverter topologies come to market, meaning that the ramp to 1,500V as the standard may take slightly longer than planned."

Aside from the trend to higher-voltage central inverters, greater emphasis on operational efficiency of PV power plants has also led to a move in the other direction for inverters – notably, the recent uptake in three-phase

Credit: GE

GE's 1500V 'ProSolar' central inverter forms part of the emerging generation of higher-voltage PV equipment.

transformer-less string inverters on sub-10MW plants and even microinverters on sub-1MW commercial rooftops and a few ground-mount projects.

Key attractions are the inherent CEC power conversion efficiencies of above 98% and high MPPT granularity, while offering modular scalability and long lifetime reliability that can provide a meaningful LCOE reduction as they transmit power to a ~1MW DC-to-AC power converter and medium voltage distribution transformer.

How the battle between central and distributed inverter architectures plays out remains to be seen. "It will be interesting to see string inverters and central inverters face off in upfront cost, DC and AC collection costs, reliability, installation, and O&M," says Campbell. "All of these factors need to be considered when choosing an inverter architecture."

Storage and power control

One capability that the PV power plant of the future will need to be able to offer is the ability to provide so-called ancillary services that help stabilise the grid. Companies such as First Solar and others have developed control systems for PV plants that, in conjunction with increasingly sophisticated inverters, enable them to respond rapidly to voltage or frequency fluctuations on the grid.

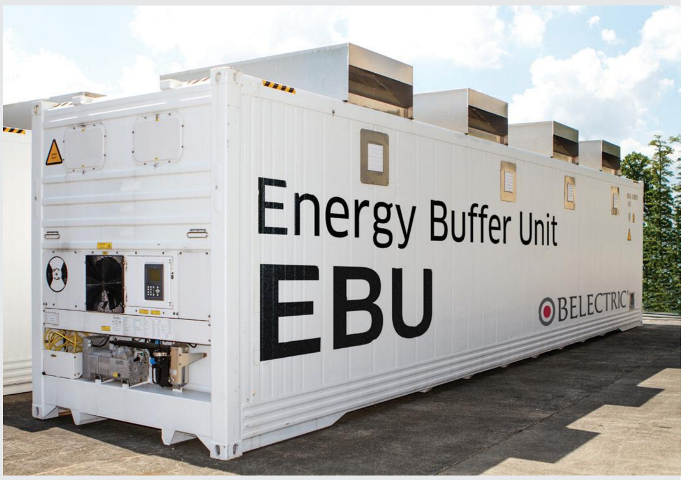
Such capabilities have so far not been a significant requirement for PV power plants given the relatively small proportion of PV on the grid. But with more PV plants being connected to the grid, that requirement will grow.

"As more and more PV plants come to the fore now, the utilities are looking for ways to stabilise the grid," says First Solar's Morjaria. "They expect the plants to perform somewhat similar to how conventional plants do in terms of providing ancillary services – things that are not currently sought after from PV plants but will become more and more important."

Much of the technology – through smart inverters, power conditioning units and sophisticated SCADA systems – already exists to enable plants to operate in this way. One particularly exciting development, however, is the coupling of these technologies to battery storage units to enable PV plants to effectively offer ancillary services night and day.

Belectric has been one of the pioneers of incorporating storage into utility solar through its Energy Buffer Unit system. This incorporates a containerised battery unit into a utility-scale PV array, allowing the array to respond rapidly to deviations in grid frequency and to sell power into the lucrative primary and secondary frequency response markets in Germany. The company is going a step further with a '3.0MegaWattBlock Hybrid', which combines all the attributes of its modular power block and EBU systems with a diesel or gas-fired generator, potentially opening up further commercial opportunities for PV.

"Ancillary services are definitely key to where this industry is going to evolve to in the future," says Bott. "If you are an asset manager, what you are looking to do is to add additional business models to your standard subsidy. So therefore if you're going to be building solar farms in the future as the subsidies drop to zero, which is what's happening at moment, then you need to add additional business models."



Credit: Belectric

Belectric's Energy Buffer Unit promises to open up new commercial options for PV power plants.

Hulk Energy Technology takes Green CIGS module power to record 324 Watts

Hulk Energy Technology Co., Ltd. (HULKet), based in Taiwan and founded in 2011, has been devoted to equipment development, product design and key process improvement. Finally HULKet launches the world's most powerful (320W~330W) CIGS thin-film solar modules, the CIGS 3000 series, which was certified by Germany's Fraunhofer ISE at 324Wp. Its conversion efficiency reaches as high as 14%, breaking the long-existing business barrier of CIGS thin-film solar products and achieving a new record in mass production in the solar industry.

Because of its material and thin-film structure, the CIGS thin-film solar module additionally possesses a Power Gain Factor (PGF) that delivers a sizeable power boost when compared to crystalline silicon modules: under the same environmental conditions and based on the same labelled power, the CIGS solar module could generate additional electricity yield as high as 26%. The power output of the CIGS module with a conversion efficiency of 13.5% is equivalent to 16.2-17.01% in mono- and polycrystalline modules.

The Power Gain Factor is determined by the following

1. Better response to UV and infrared light (spectral response); good for cloudy areas and sunny areas
2. More heat-resistant (δ=-0.23%/oC of HULKet's product which is the lowest record of global commercial solar modules, certified by TÜV Rheinland); good for hotter areas
3. Better response to light with lower incident angle, scattered light and diffused light; good for early morning and before sunset
4. Positive light soaking effect (mono- and polycrystalline modules have negative light soaking effect); it might have 4-5% higher power generation than nameplate labelled.

CIGS has many competitive advantages compared to c-Si as follow:

1. Product reliability

(1) No potential-induced degradation (PID-free); no power losses

(2) No light-induced degradation (LID-free); no power losses

(3) Absence of hot spots; no danger of consequences of hot spots ranging from fires to accelerated aging of encapsulant set.

(4) No snail trail problem; against module failure

(5) Rare existence of solder joint (as compared with hundreds of solder joints for mono- and polycrystalline)

(6) No glint/glare problem

(7) Low shadow effect (which affects electricity yield); does not induce hot spot issue

2. A vision for green energy

(1) A pleasing look: deep black colour, blends in with the environment easily

(2) Saving more energy and generating less pollution: production process does not include silicon purification and wafer processing

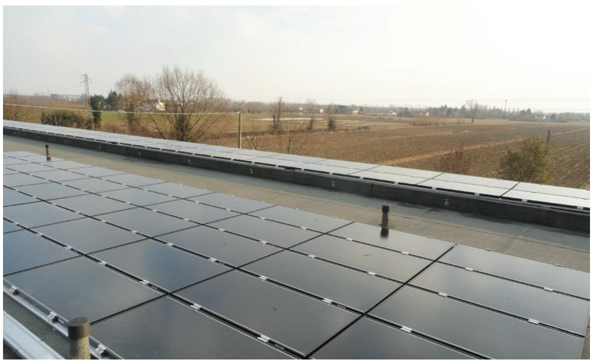
(3) Shorter energy payback time

(4) Lower carbon footprint

(5) Less consumption of raw materials and more environmental friendly

IRR/payback time is an important indicator for most investors when it comes to investment in the power sector. With the same labelled power, and assuming that price per watt is the same, because of the higher Power Gain Factor of the CIGS solar panel, the payback time for power plants using HULKet technology will be greatly reduced and IRR will be raised significantly, especially for high-powered (>320Wp) CIGS solar modules where the balance of system is relatively lower.

All HULKet's products are based on a new green design that replaces cadmium-sulfide (CdS) with a zinc-sulfide (ZnSx) buffer layer. As a result, HULKet obtained TÜV RoHS (hazardous substance) certification to ensure that HULKet's products are without toxic cadmium and without toxic lead. For four years, HULK Energy Technology has been practising sustainable manufacturing and has become a green innovator in the clean energy industry.



WORLD'S Most Powerful Green CIGS Solar Module

HULKet

- World's Lowest Power Temperature Coefficient, δ = -0.23% / °C (TÜV RL Certified)
- Lead (Pb) free, Cadmium (Cd) free, RoHS compliant
- Royal BLACK color

BoS less

IRR up

LCOE down

Power Gain Factor higher

(Yield more)

310Wp~330Wp

Cigs-3000 Series

NO.309	NO.E30	NO.E2-062
Solar Power International	**Solar Energy UK**	**PVCEC 2015 Beijing**
09/15~17, 2015	10/13~15, 2015	10/13~15, 2015

Hulk Energy Technology Co., Ltd. www.hulket.com

Trackers

Another big development in the PV power plant space is the rapid recent adoption of trackers, and this looks set to gather further pace. According to analyst firm IHS, 2014 saw a 60% increase to 4GW in the global tracker market. This year and next IHS expects 6GW of trackers to be installed in the US alone, as that market gears up for the expected deployment rush ahead of the ITC step-down at the end of 2016.

One company hoping to benefit from this is Array Technologies, which came top of IHS' 2014 tracker suppliers. The company has just launched the third version of its DuraTrack HZ product and expects to triple output this year compared to last.

Ron Corio, Array's chief executive, ascribes growth in the market to a realisation of how trackers can address the increased price pressures in the PV market. "There was more room for people to avoid the technological risk of a tracker and still make money on a PPA but as PPA rates have come down and as technology has matured, people have gotten smarter about what the benefits are of a tracker," he says.

"I think people are realising trackers work, they make sense, it's a more efficient utilisation of everything and a lower LCOE. It took a little time to prove the technology and have it follow the cost dive of solar systems in general."

Corio sees trackers as having a big future even in "marginal irradiance areas" because the incremental cost of installing a tracker he says is not that great in proportion to the benefits. "That's not just in terms of pure power production but the next step is the profile of that power production, the flatness of the power curve," he explains. "Peaking output at noon is ok but having a flatter output from morning to evening is much more desirable and most of the time that output is flatter and wider in the summer which is when [off-takers] really want to have that power."

Credit: Array Technologies

The next generation of trackers, such as Array Technologies' v3 DuraTrack, offer better performance for only marginally higher cost.

Mounting

Mounting – or racking – is probably one of the less discussed aspects of PV power plant design, but even here there is room for innovation. John Klinkman, vice president of engineering at US-based supplier, Applied Energy Technologies, says that although mounting manufacturers have driven out cost "dramatically" in recent years to around US$0.10-0.15 per Watt, the aim of driving those figures down further is a daily concern.

Klinkman says one consequence of this has been a return to standardisation in the design and manufacture of mounting products. When the industry was still young, Klinkman says few specialist racking suppliers existed. "Racking for solar was sort of taking those off-the-shelf products that maybe existed for construction or building," he says. "We then saw a lot of companies enter the market with custom shapes, adding a lot of features to try to help save installation costs or to set themselves apart. And we still have some of that, but we're also seeing a return to a lot of the common standard sections again. And cost is the driver for that."

Belectric's Bott echoes this, revealing that substructure design is the "next major step forwards" for Belectric. "Once you've standardised your block you then need to simplify the amount of fixed steel in the design," he explains.

Without divulging much detail, Bott says Belectric is developing what it calls the peg system, which he says will reduce the substructure costs by a "significant amount". "We are testing that and hoping to take some significant steps forward," Bott says.

Credit: Applied energy technologies

Racking is one area where Belectric's Duncan Bott sees further room for improvement.

The wild card

Many of the technological developments outlined above will, as Campbell puts it, offer incremental improvements to the performance and costs of future PV power plants. However, the Agora Energiewende/Fraunhofer study cited at the start does leave the door open to a future breakthrough in costs that could herald a much higher level of deployment.

As things stand, the consensus seems to be that disruption of this nature is not yet in sight. The technology currently generating most buzz is perovksite, which offers potentially much higher photovoltaic conversion efficiencies than any of the incumbents. But at its current state of development, the best prospects for perovskite appear to be using it as a tandem technology with, say, CIGS or CdTe technology, to boost their performance.

Nevertheless, in the context of what some projections have indicated PV is capable of achieving as a player in the global energy market, there is clearly hope that some wild card technology is out there that could take the industry to the next level.

"If you look at the projections of where we could be in 2050, we may be 16% of global electricity," says First Solar's Morjaria. "That's a very small number, but even to reach that number we would have to install 150GW, which we have done to this date, every year. And that's a huge challenge in terms of scaling up the business. It can be done, but it's a huge scale-up. To get to that number we are just at the baby steps in this business."

Additional reporting by John Parnell and Mark Osborne. ■