PV TECH POWER

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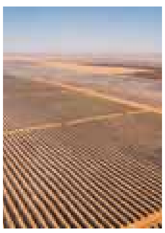

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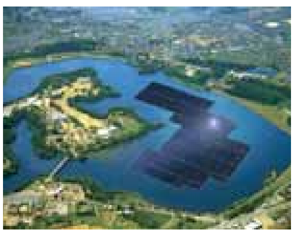

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Introduction

Welcome to the latest edition of *PV Tech Power*. As we head into a new decade, it would be easier to look back over the spectacular journey solar has walked throughout the 2010s. From nascent technology to a stalwart of power systems the world over, the last 10 years will be remembered as the decade of solar's maturation.

But rather than reflect on the journey so far, this edition of the magazine continues to push the envelope and instead glances forward. Indeed, what immediately jumps out is the level of sophistication that can be identified as you flick through the pages of issue 21 of *PV Tech Power.*

This edition's cover story comes from the deserts of the Middle East, where researchers are getting to grips with the issue of soiling and what can be done to prevent it. As you'll read (p.14), soiling is estimated to have reduced global solar energy production by as much as 4% in 2018, trimming power revenues by as much as €5 billion (US$5.5 billion). As solar PV's penetration grows, so too does the reach and impact of such issues, so the work of academics and research institutes such as QEERI to prevent and treat these issues will be pivotal.

And if it's sophistication you're seeking, then look no further than the issue of bifaciality, which litters the pages of this volume of the magazine. The technology continues to push the boundaries, helping to drive tender prices to record lows in the Middle East (p.50), while helping make subsidy-free projects bankable in markets as far north as the UK (p.56).

Of course, bifacial isn't the only technology being adopted in the pursuit of sophisticated solar. Trade body SolarPower Europe offers a glimpse at how entire swathes of the solar ecosystem is going digital, taking in new developments such as AI and machine learning (p.72). These are no longer industry buzzwords, but real solutions posing tangible benefits to the industry.

New technologies have also helped solar deploy where it hasn't been able to before. Previous editions of this magazine have charted the rise and rise of floating solar, and this has prompted renewed calls for standardisation in the field, as José Rojo Martin learns (p.82).

But this sophistication is not just seen in solar. While recent analysis has shown marked decreases in the price of lithium-ion batteries, longer-duration batteries continue to be of real interest, and our resident energy storage experts Andy Colthorpe and Alice Grundy provide a comprehensive review of new developments in this area (p.114).

At the time of writing, representatives from across the world were grappling with the lack of requisite action to help prevent climate catastrophe. The COP25 summit, held in Madrid, harked back to the landmark Paris climate accords to measure just what has been achieved since then. The answer is, evidently, not much. This has thrust significant importance on actions to be taken in the next decade, with decarbonisation of power amongst the most straightforward solutions at our disposal.

Solar, as these pages show, stands ever ready to do more than its share of the heavy lifting.

Liam Stoker
Editor in chief

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EUROPE

Spain

Spain offers subsidies in olive branch to FiT litigants

Spain's post-election government has approved a plan to offer stable remuneration to renewable projects, in a bid to defuse litigation sparked by retroactive subsidy cuts. Less than a fortnight after the country's latest snap election, ministers of the minority ruling socialist party of PSOE offered investors 7%-plus in guaranteed returns for over a decade if they scrap ongoing lawsuits over the feed-in tariff (FiT) phase-out. The decree aims to "restore stability" for those firms stung when earlier governments slashed renewable FiTs retroactively. Plants up and running since before 2013 will be offered a fixed 7.398% remuneration rate until 2031, but there is a catch. The incentives will, however, be denied to firms still pursuing litigation over the FiT cuts or those already granted compensation after winning court disputes. Those pledging to give up lawsuits or the related compensation will become eligible, the decree goes on to say.

Credit: World Trade Organisation/Flickr.

Environment minister Teresa Ribera said the rates would help restore confidence and stability.

The Netherlands

Bonus subsidy pot welcomed by Dutch solar lobby

The Dutch government has unlocked a multi-billion-euro pot of surplus renewable subsidies for 2020, targeting applicants failing to bag support in a year of grid controversies. Trade body Holland Solar welcomed the announcement by Economy and Climate minister Eric Wiebes, which detailed plans to hold a €1.5-2 billion (US$1.65-2.21 billion) new SDE+ round in late March 2020. The bonus subsidy round will sit alongside the €10 billion budget (US$11 billion) already earmarked for 2020, split between €5 billion assigned to a round pre-launched in late October 2019 and a further €5 billion for the scheme's new iteration SDE++ later next year. The extra €1.5-2 billion in renewable subsidies will be funds unused from the 2019 budget, minister Wiebes said in a letter he sent in November to Dutch MPs, where the government official set out the target of this new pot of incentives.

The UK

Top UK solar investors completes kicks off subsidy-free era

NextEnergy Solar Fund (NESF), one of the UK's largest solar investors, has completed what it claims to be first subsidy-free solar farm connected by a listed investment firm in the country. NESF confirmed that it energised the 5.4MW Hall Farm II project on 5 August 2019, the company's first project to be completed without support of subsidies. The investor said that the development gave it "industry leadership in this space", with the company having already started construction on a much larger, 50MW subsidy-free site. That project, located on the border of Bedfordshire and Cambridgeshire, is scheduled to complete before the end of the 2019/20 financial year.

Germany

Renewables records fall but German solar must accelerate further

Renewables contributed some 43% of electricity consumption in Germany in the first nine months of 2019 – a new record – however doubts remain over the country's chances of meeting future targets. New research compiled by both the Centre for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW) and the German Association of Energy and Water Management (BDEW) produced the figures. That analysis shows that, in the first three quarters of the year, solar, wind and other renewables produced around 183 billion kWh of power. Onshore wind was the leading provider of renewable power, producing 72 billion kWh, with solar second at 41 billion kWh. While Stefan Kapferer, chairman of BDEW's general executive management board, described it as "gratifying" to see renewables' contribution to German power demand grow so strongly, he warned the figures "stand in sharp contrast" to the "dramatic situation" in the growth of renewables in the country. With wind progress stymied, Dr. Frithjof Staiß, managing director at ZSW, said the country will need PV as a "second pillar" towards its renewables target.

M&A

Mitsubishi-led consortium strikes €4.1bn deal for Eneco

A consortium featuring Mitsubishi and Japanese utility Chubu is set to buy European energy major Eneco, targeting further European growth. The shareholders' committee, Eneco and the consortium reached an agreement on the proposed sale of all shares in Eneco in late November. In sealing the deal, the Mitsubishi-led consortium has fended off fierce interest from other would-be suitors including O&G major and Eneco compatriot Shell. The €4.1 billion (US$4.51 billion) deal will see Mitsubishi take an 80% stake in the company with Chubu holding the remaining 20%, pending regulatory approval of the transaction.

Utilities

Enel plots multi-billion-euro renewables investment upgrade

Enel announced a multi-billion-euro upgrade to its renewables investment programme as the utility plans to derive 60% of its power generation from renewables by 2022. More than €28 billion (US$30.85 billion) is now to be invested by the firm in renewables and clean technologies between 2020 and 2022, up 11% on its previous plan. The Italy-headquartered utility will now seek to invest some €14.4 billion (US$15.8 billion) in new renewable generation capacity, aimed at bringing forward more than 14GW of new renewables by 2022. That amounts to a 22% upgrade on its previous plan and will help reduce coal capacity significantly compared to 2018 levels. Renewables' share of Enel's generation capacity is expected to reach 60% within three years as a result.

Vattenfall to build maiden floating solar farm

Swedish state-owned utility Vattenfall is to build its first floating solar farm in the Netherlands, a country increasingly seeing floating solar appear on its doorstep. The farm is set to have a 1.2MW capacity, with construction poised to start in December. At the site of the project in Gendrigen, Netterden – Vattenfall's partner for the project – has been extracting sand and gravel for twenty-five years, creating a pond in the process. There is an electric sand pump in the water, which together with the sorting and processing equipment consumes around 2.5 million kilowatt-hours per year, of which the solar is meant to generate half. The installation of solar arrays on the pond will help drive up panel efficiency thanks to the natural cooling ability of the water, Vattenfall said.

AMERICAS

Solar manufacturing

Q CELLS to appeal US ITC patent infringement verdict

'Solar Module Super League' (SMSL) member, Q CELLS is to immediately appeal the US ITC judgement on its patent infringement case against JinkoSolar, REC Group, and LONGi Solar. Q CELLS said the appeal would be made because a correct interpretation of the (215) patent was not made by the Administrative Law Judge (ALJ) concerning the US International Trade Commission (ITC) investigation. "We as a company appreciate the ALJ's decision previewing these forthcoming initial determinations, as we intend to immediately appeal the anticipated summary determination decisions to the ITC's Commissioners," stated Q CELLS. JinkoSolar had previously announced that the ITC investigation had been concluded and no further action by the ITC would be taken.

SunPower to spin off manufacturing operations

High-efficiency solar panel manufacturer SunPower Corp is to spin off most of its manufacturing operations into a separate public listed entity, Maxeon Solar. SunPower's Board has approved the spin-off and an equity investment of US$298 million from TZS, which would give the China-based firm around a 28.8% initial stake in Maxeon Solar. Around 71.1% ownership will be held by SunPower shareholders. The deal is expected to be completed and funds provided by TZS in the second quarter of 2020. Jeff Waters, currently chief executive officer of SunPower's Technologies business unit, has been named Maxeon Solar's CEO. SunPower said that Maxeon Solar had been incorporated and would be headquartered in Singapore and its ordinary shares are expected to be traded on NASDAQ. SunPower will only retain the P-Series module assembly operations at its facility in Oregon and focus on its downstream residential and commercial businesses.

Latin America

Ecuador unveils developer shortlist for first solar venture

Ecuador has identified the handful of top global clean energy developers who will compete to deploy the country's first ever

ITC extension

US House Democrats push for five-year solar ITC extension

The US Congress' chief tax-writing committee has proposed extending the 30% federal solar investment tax credit (ITC) for five years until 1 January 2027, as part of a larger tax reform package for clean energy technologies. The Growing Renewable Energy and Efficiency Now (GREEN) Act was unveiled by the House Ways and Means Committee in a draft discussion paper that also backs an ITC for standalone energy storage. Under current legislation, the tax credit for commercial and residential solar installers will start to sunset to 26% on 1 January 2020 and to 22% in 2021. In 2022, it will expire for the residential market and drop to 10% for utility- and commercial-scale projects. Energy storage projects are currently eligible to receive the solar ITC but only if installed simultaneously and co-located with solar power generation. That would change under the draft proposals.

Credit: Wikimedia Commons

The US Congress has proposed extending the 30% federal tax credit for solar for five years

large-scale solar project. Neoen, Solarpack, Total Eren and EDP are four of the eight firms pre-selected to bid for a contract for the 200MW El Aromo solar project along Ecuador's coast, according to the government. Also part of the shortlist are Consorcio Cobra Zero-E Aromo, China Harbour Engineering Ltd., Consorcio Al Faisal-CRBC-GCL and China Huadian Hong Kong Company Limited. Selected out of 19 initial applicants, the eight solar finalists will now prepare bids for a project meant to be installed in the Manabí Province, west of the country's capital Quito.

Bolsonaro blocks Brazilian import tax breaks for solar components

Brazilian president Jair Bolsonaro has overturned a measure that would have eased the importing of solar components, potentially impacting suppliers increasingly targeting the country. In early December the controversial head of state vetoed a bill that would have exempted solar components including PV cells from a 10% imports tax. The text – already approved by Brazil's Chamber of Deputies and its Senate – is now being blocked on grounds of "public interest and unconstitutionality", Bolsonaro said. The president said he had reached the decision after consultations with Brazil's Economy Ministry, which warned the bill constituted a breach of national legislation. "Despite the legislative proposal importing Union revenue decrease, there is no indication of the corresponding compensatory measures for budgetary and financial adequacy purposes," the Ministry is claimed by Bolsonaro to have said of the bill.

Residential race

Sunrun installs outpace Tesla's again

Sunrun has once more overtaken rival Tesla on the solar deployment front, achieving a hike in installations for the latest consecutive quarter running. The San Francisco firm – which overtook Tesla in Q2 2018 as the US' top listed residential solar installer – said it deployed 107MW throughout Q3 2019, up from the 43MW Tesla achieved after bouncing back from its record lows of 29MW the quarter prior. Sunrun's 107MW install figure sees the firm achieve yet another deployment rise since the turn of the year. According to earlier updates, Q1 2019 and Q2 2018 roll-out rates stood at a respective 86MW and 103MW. The momentum appears to extend to Sunrun's solar-plus-storage offering Brightbox. During an earnings call on Tuesday, co-founder and CEO Lynn Jurich said 8,000 of these home solar batteries have been installed across the nine US states they have been launched in so far.

MIDDLE EAST & AFRICA

South Africa

South Africa plans three more 'fast-tracking' renewable energy zones

South Africa is set for three new special geographic zones for fast-tracking renewable energy projects, following the government's recent release of multi-gigawatt PV and wind plans up to 2030. The scheme to add three Renewable Energy Development Zones (REDZs) to the existing eight identified back in 2015 was announced in early November by the Council for Scientific and Industrial Research (CSIR) in collaboration with the national Department of Environment, Forestry and Fisheries. The new additions would support the Integrated Resource Plan 2019 (IRP), which aims for 6GW of solar and 14.4GW of wind up to 2030, having been gazetted by the Minister of Mineral Resources and Energy last month. The new areas have been chosen based on clean energy resource conditions, where mining industries are located, and proximity to areas in need of "rehabilitation", with local coal power capacity to be decommissioned in the near future.

Dubai

DEWA bags $0.016953/kWh tariff for 900MW of Dubai solar park

The Dubai Electricity and Water Authority (DEWA) has confirmed that it fielded a tariff of US$1.6953 cents per kWh in a tender for a 900MW plot of its 5GW Mohammed bin Rashid (MbR) solar parks – a bid it claims sets a world record for the indepedent power producer (IPP) model. The tariff comes very close to the record bid of €1.476 cents per kWh – or US $1.644 cents per kWh by today's exchange rate – lodged in a Portuguese government auction in August. DEWA's chief executive officer Saeed Mohammed Al Tayer said that the utility had achieved "a world record in getting the lowest price for PV solar power projects based on the IPP model." Al Tayer added that the 900MW tranche of the solar park will increase production capacity of the park to 2,863MW and help the emirate reach its aim of generating 75% of Dubai's total power output from clean energy by 2050.

Credit: DEWA.

The 5GW Mohammed bin Rashid solar park.

Egypt

EDF to boost foothold in Egyptian PV via KarmSolar stake buy

EDF Renewables and Egyptian developer and supplier of solar power KarmSolar have signed a strategic partnership, helping the former continue its expansion into the African state. The partnership will see EDF Renewables, the renewable energy subsidiary of EDF Group, buy an undisclosed stake in the Egyptian firm. The investment will help bankroll various KarmSolar projects around the country, expanding the portfolio through power purchase agreements (PPAs) or distribution contracts. KarmSolar already has close to 170MW of solar PV plant projects in operations, under construction and advanced development, and is considered a leading player in the emerging solar IPP space in Egypt. Ahmed Zahran, the CEO of KarmSolar said that the investment constituted "a new major step to support our growth".

Finance

China slowdown drives 'disappointing' renewable finance slump in emerging world

A slide among major countries including China crippled worldwide clean energy finance flows in the emerging world in a year when coal soared to new heights, according to analysts. Clean energy investment plummeted by U$36 billion between 2017 (US$169 billion) and 2018 (US$133 billion) across the developing world, BloombergNEF said, describing the drop as the largest ever recorded by its Climatescope survey. The analysis of 104 emerging markets identified China – where nation-wide investment nosedived between 2017 (US$122 billion) and 2018 (US$86 billion) – as a key culprit. Year-on-year funding declines in India (US$2.4 billion) and Brazil (US$2.7 billion) were also major, BloombergNEF said. The survey found the global picture brightened considerably when these three countries were removed from the analysis. With China, India and Brazil out of the equation, worldwide clean energy finance volumes were found to actually jump between 2017 (US$30 billion) and 2018 (US$34 billion).

ASIA-PACIFIC

Japan

Fukushima eyes clean energy revival via US$2.75bn wind and solar hub

Agricultural land devastated by the nuclear disaster and earthquake in Fukushima prefecture will be transformed into a major 600MW energy hub comprising 11 solar and 10 wind power plants. State-owned Development Bank of Japan and private lender Mizuho Bank are among a number of financiers that have prepared a line of credit to cover construction, local reports said in early November. The project, which is allegedly scheduled to be finished by March 2024, has an estimated price tag of JPY300 billion (US$2.75 billion). According to Nikkei Asian Review, the government also intends to build an 80-km-wide grid to connect the generated power with the transmission network of the Tokyo Electric Power Company, at an estimated cost of JPY29 billion (US$266 million). The electricity will reportedly serve Tokyo, about 250 kilometres south of Fukushima prefecture.

Vietnam

Vietnamese PM demands solar auctions in place of subsidies

Vietnam's second-round solar feed-in tariff (FiT) could be cut short in favour of an auction model after the prime minister Nguyen Xuan Phuc issued an order highlighting shortcomings in the way the Ministry of Industry and Trade (MOIT) has handled the roll-out of solar power. The shock move, which still needs to be released in the form of regulations by the Ministry of Industry and Trade (MOIT) to come into fruition, would remove FiTs for future solar projects unless they have already signed a power purchase agreement (PPA) and can become operational in 2020. As the original project completion deadline for the second FiT batch had been set at 31 December 2021, this move is likely to severely impact many projects under development.

Australia

Clean energy investor confidence hits 18-month low in Australia

Grid connection concerns, lack of federal pro-renewables government policy and transmission issues are the biggest challenges for the Australian renewables energy industry, according to a survey of more than 70 clean energy CEOs and senior executives. The latest Clean Energy Outlook report by trade body Clean Energy Council shows that investor confidence is at an 18-month low, with a 6.1 rating down from 7.1 in 2018. Industry leaders cited concerns about marginal loss factor (MLFs) as the fourth biggest business challenge, fresh from a decision by the network market operator to leave the controversial transmission and network loss pricing scheme for generators intact despite a rule change request by Adani and a strongly-worded appeal from a group of major investors.

China

China's solar installations slump to 4.6GW in Q3

According to official figures released by China's National Energy Administration, new solar capacity installations in the third quarter of 2019 slumped to only 4.6GW under new support mechanisms that were implemented mid-year. The cumulative PV installations in the first three quarters of 2019 have only reached 16GW, a record low for installs, when compared to the last four years (2016-2019). China's total cumulative installations have reached 190GW, still the world's largest installed capacity.The NEA also noted that utility-scale PV power plant installations through the first nine months of 2019 had reached 7.73GW, while distributed PV installations had reached 8.26GW. The NEA had previously approved nearly 22GW of solar capacity for the country's new feed-in tariffs scheme back in July.

Credit: LONGi.

Cumulative PV installations in the first three quarters of 2019 reached just 16GW, a record low.

South Korea

South Korea's 2.1GW floating PV venture not a military disturbance, says ministry

A huge floating solar project on South Korea's southwest coast has reportedly been given the green-light from the country's Defence Ministry after local papers suggested that reflections from the panels might disrupt operations at a nearby US airbase. The mammoth 2.1GW floating solar project, planned for the Saemangeum Seawall dyke, was approved by South Korea's Ministry of Trade, Industry and Energy (MOTIE) in late July. The plant will cover an area of 30 square kilometres on the largest manmade dyke in the world. It was specifically earmarked to be close to the airport, where business operations are low. The floating solar project is the largest of its type ever conceived, 14 times larger than the 150MW floating project in China's Panji District developed by local firm Three Gorges New Energy.

PV soiling in dry climates: causes, impacts and solutions

O&M | In arid regions soiling can greatly impact the energy yield of PV systems and drive up their O&M costs. Benjamin Figgis, Amir Abdallah, Maulid Kivambe, Brahim Aissa, Kamran Ali, Cédric Broussillou and Veronica Bermudez of the Qatar Environment & Energy Research Institute, and Klemens Ilse of the Fraunhofer Center for Silicon Photovoltaics, review the main challenges associated with soiling of PV plants globally, and the most promising techniques for dust prevention and cleaning in dry climates, drawing on research results from six years of PV performance and soiling studies at QEERI's Outdoor Test Facility in Doha

In 2011, the government of Qatar recommended creating a solar-energy test station to assess the effect of local climate conditions on PV systems. This aimed to study whether the high temperature, humidity and dust could cause PV reliability risks, which had to be quantified and mitigated prior to large-scale development of PV plants. In 2012, the Outdoor Test Facility (OTF) was opened at Qatar Science & Technology Park [1].

Seven years later the OTF, now operated by Qatar Environment & Energy Research Institute (QEERI), has tested over 60 PV modules and found that Tier 1 modules themselves generally cope well with the harsh conditions (they show little electrical or mechanical degradation), but dust accumulation is a challenge. At the OTF, soiling causes the power of PV modules at 22° tilt to decrease by 10-20% per month. The soiling can, in extreme cases, form a homogenous whitish layer that appears visually opaque (Figure 1 left). This dust can however be quite effectively removed by rain, when the rainfall is heavy enough to dissolve the water-soluble components and wash away the particles (Figure 1 right). Actually, after 234 days without rain — the longest dry period experienced on the OTF — the power of never-cleaned modules decreased by 70% so the dust layer was, in effect, still 30% transparent.

Qatar's case is not the most extreme; soiling rates can reach 1 to 2% per day in some parts of India and China (Figure 2). ("Soiling rate" is typically defined as the decrease in PV performance ratio per day, due to accumulation of pollutants such as dust, pollen, or other organic matter.)

Figure 1. Examples of soiled modules (left) and modules naturally cleaned by heavy rain (right). These are the same test beds viewed from opposite side at the QEERI Outdoor Test Facility

A recent comprehensive review of the subject by Ilse et al [2] showed that in dry climates soiling rates are typically in the order of 0.1-1%/day for PV, with the most severe cases reported for concentrated solar power plants (CSP) due to sensitivity of the collector to the optical pathway. Many other locations, including parts of the US, southern Europe and Australia have lower but still problematic rates, in

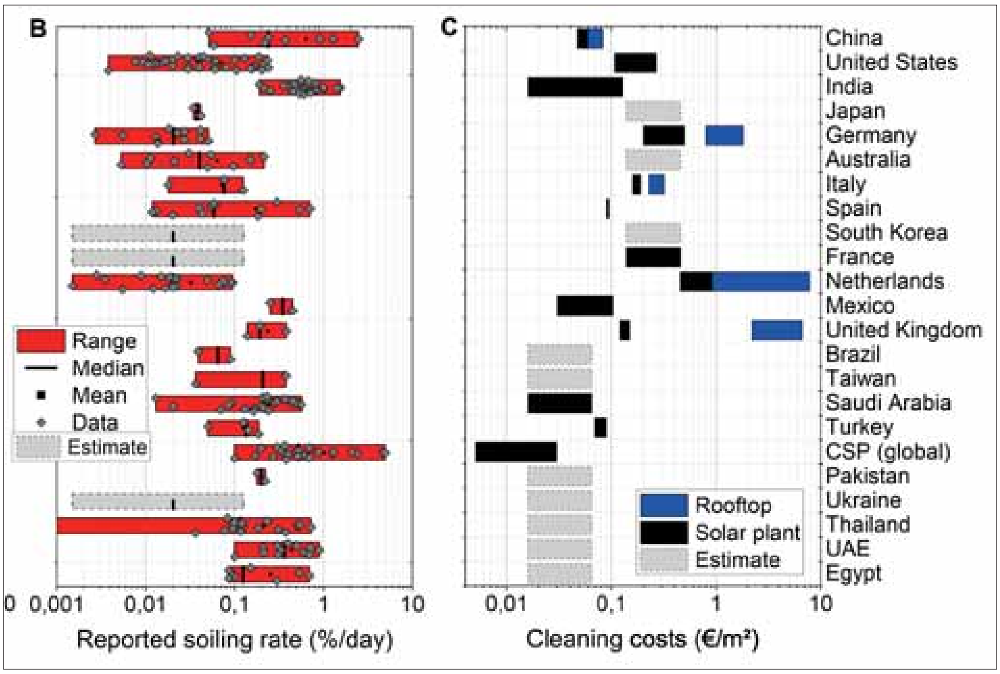

Figure 2. Examples of soiling rates and cleaning costs around the world [2]

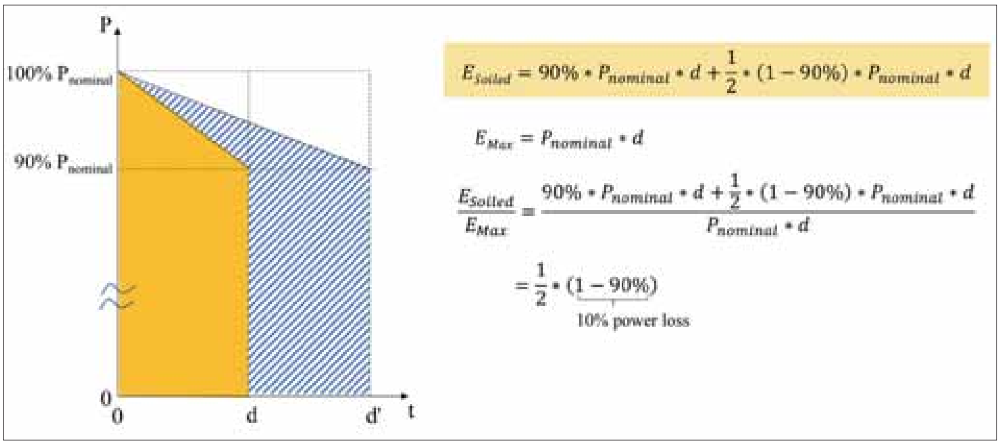

Figure 3. Typical power loss due to soiling as a function of time (yellow=high soiling; blue=moderate soiling) and calculation of energy loss which is half of power loss

the region of several percent per month. In other words, soiling is a concern for PV plants in much of the world. It is more severe in deserts due to high dust concentration and absence or rain. This results from almost permanent high atmospheric pressure that either prevents clouds forming or depletes them of water. Since few clouds form, they do not reflect sun light back to space, which increases both solar irradiance reaching the ground and moisture evaporation. At the same time, it severely limits the amount of rainfall. Thus, the ground is easily eroded, which generates inorganic dust particles prone to be suspended in air and re-deposited onto PV modules.

Soiling increases the levelised cost of energy (LCOE) in two ways. First, the dust layer reduces the amount of light entering the module, thus lowering the electricity generation. Second, cleaning expenses increase the operation and maintenance (O&M) costs needed to achieve energy yield targets. It is estimated that soiling reduced solar energy production by around 3-4% globally in 2018, causing revenue losses of €3-5 billion(US$3.3-5.5 billion) [2]. Cleaning costs for ground-mounted PV plants vary greatly worldwide (Figure 2) but are typically in the range €0.01-0.1 per m² for the most-affected countries. These figures reflect the cost of manual cleaning, which is still the norm even in utility-scale plants (emerging technological solutions are discussed below). This cost range is for ground-mounted projects; rooftop cleaning costs considerably more. The economics of PV plants can, in principle, be improved by applying soiling knowledge: more accurate prediction of soiling losses (and thus energy production) at the planned site, and more efficient scheduling of cleaning.

"It is estimated that soiling reduced solar energy production by around 3-4% globally in 2018, causing revenue losses of €3-5 billion"

The decision on how often to clean is driven by project-specific parameters — e.g. soiling rate, electricity price, labour cost — so there is no "one size fits all" optimum frequency. According to Dr. Raed Bkayrat, formerly head of First Solar in the Middle East and now with cleaning-robot manufacturer NOMADD, utility PV plants in severe soiling locations such as the UAE are cleaned around 40-45 times per year in order to keep soiling energy loss below 3%, while in milder locations such as Jordan the frequency is around 25-30 times per year.

There are many methods for characterising PV soiling [3] hence terminology is important: if cleaning is done when the "power loss" of the PV plant (an instantaneous measure) reaches say 10% then the average "energy loss" since cleaned (a time-cumulative measure) will be half that (5%), assuming a constant daily soiling rate and the same irradiation each day. This simplified estimate does not depend on the constant soiling rate, as a lower rate will mean that the 90% power limit will take more days to be reached (d') but the overall energy loss will not change (in Figure 3 d or d' is the number of days needed to reach the power limit 90% *$P_{nominal}$).

It is worth asking the question — what if one never cleans at all? Even in deserts, it rains occasionally. In Qatar, we found that a "never cleaned" test array at the OTF produced 23.5% less energy over five years than a clean reference array. From these sample statistics (23.5% average energy loss without cleaning, and 70% power loss in the worst case – Figure 4), the idea of installing extra modules and relying only on rain cleaning does not appear realistic for typical desert PV projects. Indeed, even with low-cost modules available, the PV plant should ideally have a reliable (if not constant) total power in order to limit the costs of grid balancing. This situation could evolve in the future when new grid management systems or storage solutions become more cost-competitive but seems unlikely for deserts, especially during summer as it is when the power load curve matches best the PV production curve due to air conditioning demand. Thus, since cleaning in arid regions is unavoidable,

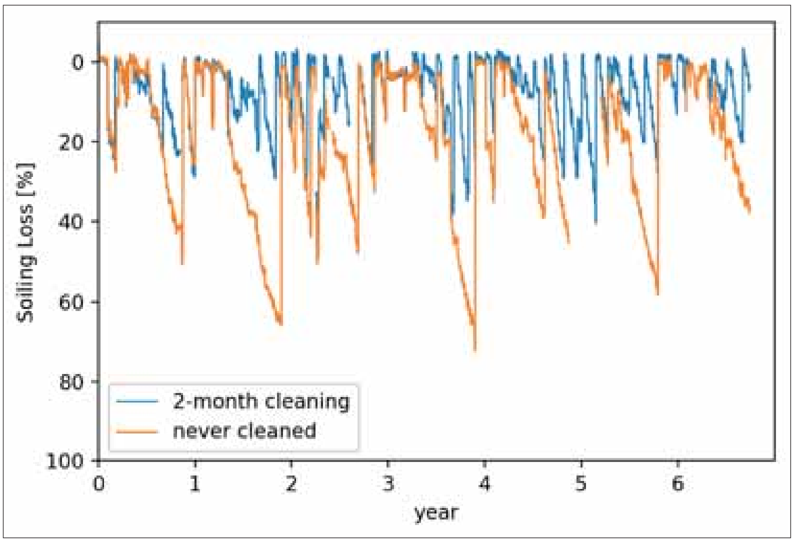

Figure 4. Soiling losses measured from 2013 (year 0) for arrays cleaned every two months (blue) and never (orange), in Doha

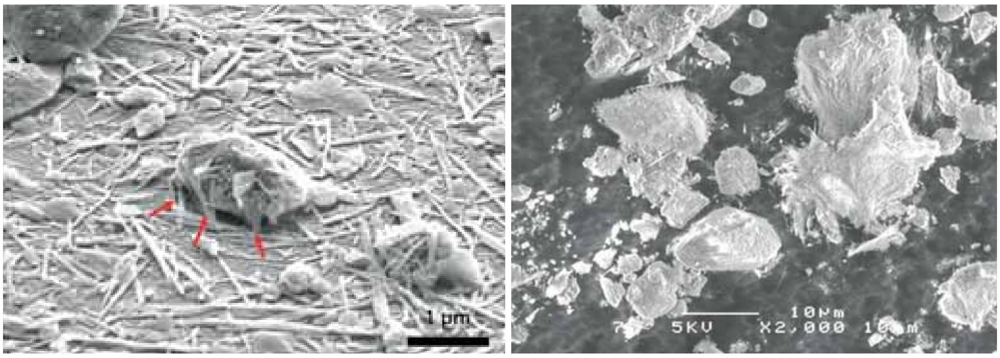

Figure 5. Scanning electron micrographs, at different scales, of dust particles cemented by palygorskite needles to glass substrates via natural outdoor exposure in Qatar (left [5], right [7])

the industry's goal is to bring down its cost and to optimise its frequency so that O&M cost is minimised and electricity production is maintained at high level.

Physics of soiling in deserts

What causes soiling? The answer appears simple: dust settling on PV module surfaces. But dust deposition is only half the story; more important is whether the dust sticks to modules after depositing (whether it can slide off or be removed by wind or rain). Here the physics is more complicated. What is the dust composed of? What is its size and shape? If wind can entrain dust particles from the ground, why doesn't it remove them from PV modules?

The "stickiest" soiling scenario is when dust is fine and contains soluble matter, and the climate is humid. Small particles (diameter less than several microns) are essentially immune to wind removal, because the aerodynamic drag force scales with the square of particle size, while the adhesion force scales with particle size itself. For this reason dust accumulating on PV modules tends to be finer than the surrounding airborne dust – large particles are blown off, but small particles remain [4]. Soluble environmental species, such as salts and nitrates, dissolve in the soiling layer under high humidity or dew at night. When the surface dries out again during the day, this matter "cements" dust particles to the module. Micrographs of cementation (Figure 5) vividly show that Qatar's dust chemistry and climate form palygorskite needles that are present on the glass surface and attach larger dust particles to the surface [5]. Even when the dust contains little soluble matter, capillary adhesion is seen at quite moderate humidity levels, which captures dust particles on the surface [6].

The physical link between humidity and dust adhesion is not just an academic curiosity; it translates to PV soiling rates observed in the field. At QEERI's OTF in Qatar, there is seasonal correlation between the soiling rate of PV modules and the proportion of days in which relative humidity exceeded 75% (Figure 6). To directly test the theory that eliminating condensation would reduce soiling, Ilse et al [8] performed an experiment with a heated glass coupon and an unheated reference one, and found that the heated coupon accumulated 65% less dust over four weeks. Further experimental evidence of the moisture/soiling connection came from an analysis by Fountoukis et al [9], which found high correlation (R^2 of 0.94) between the experimental performance ratio loss due to soiling and a mathematical parameter based on meteorological parameters PM10 and a sigmoid function of relative humidity (RH):

$$\textit{Aerosol mass predicted to cause soiling} = \textit{cumulative } PM_{10} \,/\, [1+\exp(-a(RH-b))]$$

where *a* and *b* are fitted constants.

We have seen that adhesion of dust to PV modules is governed by the dust properties and moisture. The rate at which dust settles on modules in the first place is influenced by many more factors. Some are features of the local environmental, but others can be controlled by engineers. A study [10] by Micheli of NREL found that — in the US at least — the best environmental predictor of variation in long-term PV soiling rate at different locations was PM2.5 (concentration of aerosol particulate matter up to 2.5µm). At the timescale of minutes, on the other hand, field microscopy at the OTF found that the accumulation rate was most dependent on wind speed [11]. These results are not contradictory but suggest that for site-selection purposes and O&M estimation, the local average PM concentration and wind speed are key factors for the PV soiling rate. The instantaneous physical motion of dust particles, on the other hand, is governed by particle size and wind speed.

Design of the PV plant can also influence the soiling rate. A major factor

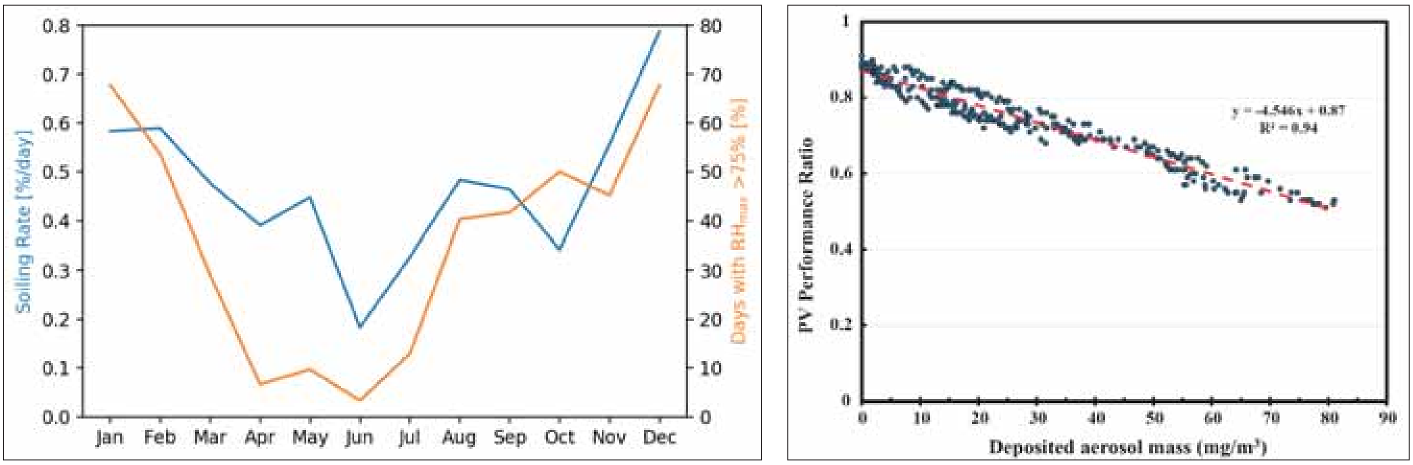

Figure 6. Left: seasonal correlation between humidity and PV soiling at the QEERI OTF. Blue line: daily soiling rate. Orange line: Percentage of days in the month in which the maximum relative humidity reached 75%. Right: PV performance ratio experimentally measured as a function of the aerosol mass (mg/m³) predicted to cause soiling based on cumulative PM10 measurements and a sigmoid function of relative humidity (meteorological data) from [9]

Figure 7. Test trackers with enhanced tilt ranges at the OTF in Qatar. Soiling was greatly reduced by vertical night stowing, but there was little gain from tilting to enhance dust resuspension during wind [13]

is tilt angle: the primary driver of outdoor dust deposition is gravity, and studies of PV soiling universally find the most severe loss at horizontal tilt and little loss when vertical [4]. We recently also determined [12] that soiling tends to be greater when the wind direction is from "behind" a tilted module (i.e. from the north, for a south-tilted module), all other conditions being the same. However, in practice the PV engineer can make little use of such information — the tilt of fixed modules is selected to maximise annual plane-of-array irradiation, and rows are spaced for shading and accessibility requirements.

As use of horizontal single-axis trackers (HSAT) grows, it raises the possibility of using their tilt to combat soiling. We conducted tests with full-size modules on HSAT at the QEERI OTF (Figure 7). The easy-to-implement approach of stowing the tracker at maximum tilt toward the night wind, rather than away from the wind, could simply (although slightly) reduce soiling [13]. Pushing this concept into less practical territory, stowing trackers vertically at night could reduce soiling by more than 40%. Also, HSAT can be "friendly" to PV cleaning by tilting to a steep angle during manual cleaning, or to horizontal when cleaning robots are used.

Anti-soiling technologies

Although manual cleaning of PV systems is still the most common method, it is desirable to minimise manual labor and a range of technological solutions are being developed. Those at the commercial stage are automated cleaning machines (robots) and anti-soiling coatings, while electrodynamic shields (EDS) are pre-commercial. Overviews of each follow.

Cleaning machines

PV cleaning machines have been available for many years. The first were truck-mounted, wet-brush systems, and these continue to be widely used where water is abundant. With the large deployment of PV in arid regions, models have been introduced that are waterless, fully autonomous, and run along the array (rather than using a truck), see Figure 8. A recent survey by Solarplaza [14] listed 16 commercial PV cleaning machines, with wet systems developed for Europe, USA and Japan, and dry systems for those markets and also arid ones. A common autonomous design is a long rotating brush that spans the width of the PV array and is guided by its edges. Robots also exist that are smaller than the width of the array and crawl along the modules themselves, but they are not widely used in commercial PV plants.

Advantages of robots include: they are effective at removing dust, can be run frequently, and are built from robust existing parts (motors, sensors and controllers). Because they have significant up-front cost but low operating cost, and manpower can be required to move them between PV rows, the economics of robots favor long, continuous PV rows and running them relatively often to maximize electricity generation. However frequent dry brushing raises the risk of abrasion of PV coatings, discussed below.

Specialised robots also exist for horizontal single-axis trackers and since robots are most efficiently deployed on long, continuous PV arrays, those trackers have been improved by manufacturers such as Soltec, Nextracker, PV Hardware, Soltigua and others to offer such long span continuous surface. These long-span trackers are currently being optimised to ensure wind load stability and to increase electricity production through the use of bifacial modules with reduced shading on the back side.

Credit: NOMADD Desert Solar Solutions

Figure 8. Dry-brush automatic cleaning machines are gradually being deployed at commercial PV projects in desert regions.

Coatings

Anti-reflective coatings have been widely used on PV modules for several years and in 2019 are present on more than 90% of all crystalline silicon modules [15], although their durability is still being improved to last up to 25 years. Efforts are also being made to develop anti-soiling coatings, which aim to reduce particle-to-coating adhesion forces in dry conditions or increase dust removal by water (rain or spraying). One approach has focused on TiO_2, used commercially in building glazing, which has a photocatalytic effect that breaks down organic matter. However, its light transmission is inferior to other coatings, and, in deserts, dust mostly comprises inorganic minerals. Another route has been to use hydrophobic materials, based on fluorine or methyl compounds, however such surfaces are prone to contamination and degradation. The main strategy being pursued at the moment is use of silica nanoparticles, whose properties are tuned by their morphology (roughness and voids) and binder.

In practice it has proven difficult to produce anti-soiling coatings that are effective, highly transparent and durable. To date only one large company (DSM) has fully commercialised and marketed an anti-soiling coating for PV modules, which uses silica nanoparticles, applied to solar glass in the factory. The product is designed to slow soiling so that the interval between cleanings is extended. Several smaller companies have developed coatings designed to be applied in the field, but to our knowledge they have not been widely adopted for refurbishment of existing PV plants.

EDS

Electrodynamic dust shields (EDS) aim to dispel dust particles from PV modules using local electric fields. The fields are generated by fine, interdigitated electrodes embedded in a transparent film on the front of the module. They are dynamic in that they are applied as periodic pulses, sometimes in traveling waves, so that particles are driven downward on a tilted surface. The concept first appeared in the 1970s for powder transport, was developed by NASA for PV panels on Mars and the moon, and over the past decade for PV. Although the technology has been well demonstrated in the laboratory, it has proved less effective in field tests mainly because of humidity. A recent field trial with full-size modules in Saudi Arabia reported an average cleaning efficiency of 32.1% [16], while a trial with mini-modules in Qatar [17] achieved in 16-33% removal. Based on current performance then, occasional cleaning using other methods is still required with EDS. Also, their sophisticated control electronics and installation of module electrodes raise cost and pose reliability challenges.

Abrasion

A key take-away from the above is that PV in dry climates will be cleaned with brushes for the foreseeable future: in the short term, cleaning machines will increasingly replace workers, and this will likely increase brushing frequency. In the long term, coatings and EDS might be deployed, which reduces brushing frequency but will not eliminate it. Since almost all PV modules now have anti-reflective coatings on their front glass [15], it is of great interest whether brush cleaning damages the coating (faster than normal exposure to the environment). Another question is how to test and compare coatings' abrasion resistance, given that existing test standards do not well simulate PV cleaning.

It is not straightforward to measure PV abrasion. One challenge is that the same coating material can have different properties when applied to a test coupon versus a full-size PV module. However, the most sensitive characterisation tools, such as photometers and profilometers, usually cannot accept full-size modules. Being tempered, the front glass of PV modules cannot be cut into smaller pieces for analyses. Anti-reflective coatings typically increase module power by around 4%, so even in the most extreme case (complete removal of the coating) the abrasion may be difficult to detect, especially from field monitoring. Another challenge is accelerated testing. This is needed because abrasion in normal field operation will not appear for months or years. One could simply conduct cleanings more frequently, say several times per day, but this would eliminate the dust layer that builds up between "normal" cleanings and may affect scratching. QEERI is starting an abrasion study with full-size modules combining realistic field exposure and cleaning with sensitive lab characterisation tools.

An abrasion study [18] using coupons, in which glass samples with various coatings and cleaning methods were tested in Dubai, confirmed that dry brushing was the most severe method and that coating abrasion resistance varied widely. But so far there have been no reports using commercial PV modules and cleaning practices in a desert environment that conclusively show whether (or how quickly) cleaning abrades the modules coatings. Meanwhile, the National Renewable Energy Laboratory is developing an international test standard for PV abrasion which should enable meaningful comparison of coatings' durability. ■

Acknowledgements

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Turn to p.22 for further exploration of how the solar industry is embracing new cleaning technologies.

DustIQ
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Soiling measurement with a maintenance-free system

"Nothing ever stays clean" is a common frustration, particularly with equipment installed outdoors. It picks up dust, mud, soot, salt and many more contaminants that can be generically called 'soiling'. In most cases, the collected contamination on your car or home is just a nuisance. But when you're running a solar energy park this soiling, or 'dust' as it is often referred to, is much more important. Soiling = power lost = revenue lost; maybe penalties incurred for under-performance.

Soiling Loss

Some of the incoming solar radiation is reflected, scattered and absorbed by the dust accumulated on the solar panels, reducing the yield. The logical solution is regular cleaning. But, cleaning from thousands to millions of PV panels is expensive and time consuming; so a well-informed decision has to be made regarding when and where to clean and how often.

For that decision, one needs to know the quantity and the value of the solar energy not reaching the silicon cells. The energy not passing through the glass of the PV panel is called the Transmission Loss (TL). Armed with the TL it is then possible to calculate the soiling loss and revenue loss and decide if it's worthwhile cleaning.

Until recently, determination of the soiling loss was based on a 'guesstimate', experience or on a measurement system with two identical PV panels. One panel is left untouched, becoming soiled, and the second panel is kept clean as a reference. This measurement can be accurate, if the panels used are similar to those used in the park, as it measures the real energy loss. However, accurate measurements need a lot of sun at close to normal incidence to the panels, and therefore only work well about two hours before and after local solar noon, and with little or no overcast.

One soiling measurement point might not be sufficient

Keeping the reference panel clean requires strict planning; it might need to be daily, using manual labour or an expensive robotised system that will need power, often a water supply, and always

maintenance. Because of the operational issues, size and price two-panel systems are usually installed at a single location only. This is often not representative of the soiling at a typical panel, nor does it reflect the fact that the rate of soiling varies across the park.

OSM technology

To circumvent these difficulties and provide affordable, distributed measurements at multiple points, the people working on the unique Optical Soiling Measurement (OSM) technology at Kipp & Zonen have developed a new measurement approach.

DustIQ does not rely on the comparison of soiled and clean panels, but measures the Transmission Loss of the panel glass directly; day and night, with and without sun. The innovative OSM principle is based on emitting modulated blue light from an LED beneath a glass window and measuring the light reflected from the surface. The more soiling there is on the surface the more light is reflected.

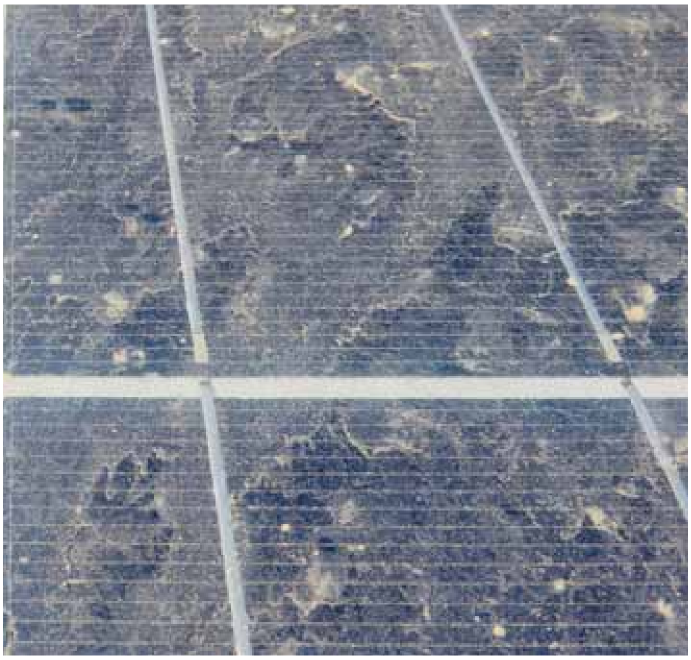
Rigorous testing with dust samples from all over the world has shown a consistent relationship between the intensity of reflected light, the amount of dust accumulated and the subsequent energy production loss of a PV panel. DustIQ can measure the Soiling Ratio within 1%, has no moving parts and needs no regular maintenance; just clean it at the same time as the panels around it.

Soiling Ratio is the accountable value

Following the requirements of the IEC 61724-1:2017 standard "Photovoltaic system performance Part 1: Monitoring", the DustIQ measurements are reported as a Soiling Ratio (SR). The SR is defined as "the ratio of the actual power output of the PV array under given soiling conditions to the power that would be expected if the PV array were clean and free of soiling". When completely clean, the SR is 100%.

Details on DustIQ

DustIQ is small (99 x 16 x 3.5cm), light (4kg) and easy to install. The materials used are the same as in typical PV panels; the textured glass and coatings, EVA sheets and aluminium frame. DustIQ has two identical sensors with independent signal outputs so that if there



is unusual local soiling, such as bird droppings, it can be detected. The measurements are transmitted digitally over RS-485 in industry-standard Modbus® RTU format.

PV panel temperature greatly influences the cell performance and it is critical to monitor it. An IEC / NREL compliant sensor has its temperature measurement integrated into the DustIQ data output.

Map of soiling across a solar plant

Following IEC61724-1:2017 recommendations, it is advised to deploy several DustIQs over a solar park to monitor the variations in soiling patterns. The number of instruments depends on the size of the solar park and ranges from one per 5 MW for small parks to one per 50 MW for 300 MW parks and larger. Using several DustIQs enables a precise soiling map of the complete solar park to be drawn and enables and localised cleaning to be scheduled, thus saving a lot of time and money.

Interested and keen to know more?
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for downloads subscribe to the DustIQ mailing list.

Keeping it clean

Cleaning | As detailed in the previous article, research into the soiling of solar modules is shedding new light on the problem, its impacts and the best solutions. Sara Verbruggen looks at some of the available latest technologies, the economics behind them and how they are being deployed in the field

Credit: Ecoppia

What's the best approach when it comes to reducing panel soiling in dry, dusty environments? While cleaning panels using water is the most effective way of eliminating soiling, in a growing number of markets a dry cleaning approach is more suitable, with a market that is evolving to sustain various solutions spanning low-tech and relatively low investment tractor-mounted brushes to a fully automated service, administered by sophisticated technologies.

Market drivers and cleaning approaches

As the cost of solar technology has fallen, this has helped unlock demand in emerging markets. In many instances such markets tend to be in dry, subtropical regions, such as the Middle East and North Africa, India, and Latin and Central America.

Drivers for dry cleaning of PV modules can include regulations prohibiting or limiting water consumption, water scarcity, high water rates or costs associated with water infrastructure, such as pumps and reservoirs, if sites are remote from water sources. Where there is access to water for cleaning, low-tech manual methods can be used. But these can impact operational expenditure, depending on local labour costs and other factors. And as detailed in the previous article, soiling is a higly location-specific phenomenon, meaning the final choice of cleaning method and strategy will be informed by the specifics of individual projects.

From a solar asset owner or operator's perspective, cleaning solutions are broadly categorised in terms of capital expenditure (capex) versus operational expenditure (opex), according to Dr Marc Korevaar a scientist in the research department at solar instrument producer Kipp & Zonen.

New cleaning technologies are helping developers improve project yield and cut O&M costs

"Manual cleaning has the lowest investment, or capex, cost but highest opex, due to the cost of labour. Truck-based – semi-automated – cleaning has an intermediate investment cost and intermediate labour opex and tends to be used in places such as the US, parts of Europe, as well as parts of the Middle East," he says.

Brush cleaning involves a driver manoeuvring a truck or tractor, mounted with a crane jib and brush, to move along a row and clean each panel.

"Fully automated, or robotics-based, cleaning, has the highest investment cost and the lowest labour opex and tends to be used in places with high soiling where water is also scarce and so is expensive as well as where labour costs being higher," Korevaar says.

"One of the drivers for fully automated cleaning, which has emerged in more recent years, that we are seeing, is the general trend towards larger solar plants. Labour costs, as part of operations and maintenance (O&M) opex, can be significant to keep modules clean at sites that are hundreds of megawatts in size."

Anat Cohen Segev, vice president of marketing at cleaning robot manufacturer, Ecoppia, says vice says automated robotics cleaning technology provides benefits to solar asset owners in two ways: "Cleaning increases energy output of solar panels, thus higher revenues from increased output. This can be beneficial where installations are getting subsidy payments, as additional MWh generated results in subsidy payment on top of the electricity price.

"O&M opex savings are also realised through elimination of labour costs and water and associated infrastructure costs of getting water to site, storing it and because there is also less vegetation to maintain as well."

Korevaar thinks that the growing awareness among operators of the amount of losses due to soiling that can occur is leading to more interest to measure and understand causes of soiling and levels of soiling and using this data to decide on the most suitable dry-cleaning approach.

The same Fraunhofer CSP study cited in the previous article, estimating that the global solar industry loses €3-5 billion annually from soiling, also predicts that by 2023 that loss could increase to around €4-7 billion. This is partly down to more solar capacity being installed in high insolation regions, also with high levels of soiling, such as China and India, where lower prices paid for electricity can act as a disincentive to clean modules.

Quantifying soiling

Kipp & Zonen's DustIQ system for measuring and monitoring soiling from dust is used by around 60 solar asset owners and developers globally, according to Korevaar.

"Understanding potential losses from soiling has helped stimulate interest in how soiling levels can be mitigated during solar plant operational phases," he says.

Over large solar park sites, DustIQ can be used to measure differing soiling levels across the entire site. "For example, proximity to roads, or certain wind conditions, can result in higher soiling in localised areas.

"We are generally seeing a demand for measuring soiling in all regions that are dry and therefore have a lot of natural soiling. Furthermore, regions where there is manmade soiling, due to factories or mining activity, for example, creates additional need for using tools to accurately quantify soiling levels."

DustIQ customers are primarily engineering, procurement and construction (EPC) companies that are building new plants, as well as O&M providers retrofitting soiling sensors at PV plants. The measuring system is also applicable in solar plant development, during site selection.

"For example, where a developer may have two or three potential sites for development, the sensors and measuring instruments can be installed around the sites to collect data on the different soiling levels at each site, which can then feed into criteria when deciding which site to develop," Korevaar explains.

The measuring system can also be deployed to inform solar plant design to mitigate or reduce the level of soiling, by planting vegetation as a screen from dust and particulates around the edge of the solar park, or by installing panels at higher levels, where soiling is reduced.

DustIQ can also be deployed in operational solar facilities. Operators can use it to measure dust and particulates to assess soiling levels and then use the information to inform module cleaning schedules and which approach is the most relevant. "They can decide if a high capex but low opex or low capex, high opex method is best," says Korevaar.

Approaches and cleaning techniques are influenced by several factors. For example, in very dry and arid regions, such as south-west USA where condensation (dew) levels are low, panel soiling is less comparable with parts of the Middle East, where dew or condensation on the panels attracts dust and dirt to adhere to the panels and for soiling to build up, requiring more cleaning.

Other factors include cost of water as well as associated infrastructure. "In south-west USA, water costs are cheaper compared with other arid, dry regions, such as Saudi Arabia, where soiling levels are not only high, but water costs are high too, making dry-cleaning robots more feasible," Korevaar says.

Robotics versus brush cleaning

Norwegian developer Scatec Solar's portfolio encompasses PV plants in more than 10 countries, in a range of locations. In parts of Europe where there is rainfall in sufficient quantity, most soiling is washed away, so minimal cleaning is needed. But the company also owns plants in Egypt and Jordan where there is very low rainfall throughout the year, allowing dust and other particles to build up significantly and requiring continuous cleaning.

Scatec Solar senior vice president for O&M, Pål Strøm, says: "There is no one-size cleaning solution. Selecting a solution comes down to a capex and opex calculation, which takes into account the detailed characteristics of the site and performance of the cleaning solution."

Before a project is constructed Scatec Solar carries out a detailed site study, to model soiling levels, based on measurements of rainfall and humidity levels, wind speeds and direction, dust and soil particle analysis and vegetation type.

Then, the most suitable cleaning approached is assessed. Several factors are evaluated, for example cost of labour, cost of water, fuel cost, as well as cost of water infrastructure, according to Strøm.

"Cleaning solutions fall into three main categories. Manual, which is where people are employed to clean panels. Trucks or tractors mounted with brushes, which can be used for wet or dry cleaning. Then there is fully automated cleaning using robotics solutions," he explains.

In low soiling environments, where manual cleaning is a cost-effective solution, Scatec Solar outsources to a subcontractor. "Where we have PV plants in drier and dustier regions, historically the company's main approach has been

Semi-automated, truck-based cleaning has proved to be a low-risk, cost-effective solution, but is likely to be superseded by robotic technologies

Credit: Scatec Solar

to use brush-mounted trucks as it is a low risk and proven approach, as well as being cost-effective," he adds.

This method has been deployed at the company's plants in Brazil and Egypt, where soiling rates are high in both locations. "Scatec Solar will invest in the tractors and equipment and have operators to carry out the cleaning, which is more of an insourced approach."

Scatec Solar is planning to deploy its first robotics solution at a 117MW plant currently under construction in Argentina, expected to be completed in first quarter 2020.

"The key driver for going with a fully automated robotics solution is to increase yield. Even though the opex is low, robots require significant capital investment in this equipment, so in order to rationalise that high capex, the solar farm needs to be in an environment with very high soiling levels, where continuous cleaning is required," Strøm says.

There are different investment and ownership models that are offered by the providers of robotic cleaning systems. In some cases, maintenance can be outsourced to the providers of these systems, according to Strøm.

"Once we have gained more operational experience with robotics solutions, we will reassess our strategy with the view to introducing automated cleaning, where profitable, at our existing plants in markets, such as Egypt. For new plants, robotics is already part of the operational concept where profitable.

"It is important to mention here that where PV plants are being operated in emerging economies, the trend towards automated cleaning poses asset owners and operators with a dilemma, which is that it takes away jobs," Strøm adds.

Solar technology does not require much manual maintenance activity, compared with other technologies, such as wind, for example. Manual or even truck-based cleaning employs people in local economies.

"It is not such an issue for new projects in development where the market is highly competitive and the economics in specific locations could favour automated cleaning over other more conventional approaches to optimise yields and efficiencies, but it is why we are carefully assessing how we roll out automated cleaning, using robotics solutions, at some existing solar locations with high levels of soiling, such as the Middle East and North Africa."

Strøm says other approaches to minimising soiling levels have been considered, for example, stowing panels at a steeper angle/gradient at night. "But you also have to consider the wind factor also," he adds.

Demand for robotic cleaning

Ecoppia has developed a fully automated robotic panel cleaning platform, which eliminates labour costs associated with panel cleaning, as well as water and related logistics and infrastructure costs.

The company's technology is the only IFC/World Bank-certified robotic cleaning system. If a developer is seeking IFC financing for its solar plant, then Ecoppia is the only robotic panel cleaning system it can use.

Developer clients include SoftBank, Fortum, EDF, Engie, Actis and Renew Power. The technology has also been tested and endorsed by solar module manufacturers, including First Solar.

Return clients include Japan's SoftBank, where Ecoppia recently provided its cleaning robots for a 580MW plant in India.

Over 2GW-worth of ground-mounted solar modules are cleaned by Ecoppia's robots, with a significant portion of this capacity installed in India. Other markets include the Middle East, south-west USA and recent projects in Chile. The company also has a 5GW global pipeline of secured projects at various stages of development, in markets in Latin and Central America, the USA, the Middle East and India.

"Demand is very high in Latin and Central America, as well as in Spain, in Europe. We're also seeing interest from Australia, which we are targeting," says Cohen Segev.

Initially, Ecoppia targeted markets where water scarcity has been an issue or where logistics and cost of getting water to sites for cleaning is challenging, according to Cohen Segev.

"Today, we see that there are other key drivers for using robotics cleaning. In dry, dusty regions with high levels of soiling, solar asset owners are looking to eliminate labour costs to reduce overall O&M costs, for example. Robotic cleaning can also recover sites instantly post dust storms, as well as provide operators with clear visibility for cleaning efficiency and cost through the project lifetime.

"As PV plant projects increase in size manual cleaning is simply not sustainable, and not feasible logistics wise."

Ecoppia provides two robotic systems.


Credit: Ecoppia

Ecoppia's T4 model is aimed at single-axis tracker installations

The E4 robot is for fixed tilt and seasonal tilt solar installations able to clean long arrays during each nighttime operation. The T4 robot for single-axis tracker installations was launched earlier in 2019. According to Ecoppia, global demand for the T4 is in excess of 1GW.

Cohen Segev says: "Clients want an end-to-end solution for their entire portfolio. They often have projects in different geographies that span use of fixed-tilt and single-axis tracker. The T4 allows us to fully support our clients with a dedicated solution for each technology, to maximise cost effectiveness. In addition, it allows us to expend to additional markets."

Though Ecoppia supplies retrofit projects, the company is becoming increasingly involved in greenfield projects from the design phase, according to Cohen Segev.

"As panel cleaning is a large part of O&M costs, project developers will factor in robotic cleaning as criteria for designing arrays and layouts in order to minimise robots required. In the case of some clients, we're involved at the tendering stage.

"Where our input is considered for the design phase of a PV plant, it can result in designing arrays to keep number of robots to a minimum, to keep costs down. In some cases one robot would be needed for 3-4MW in a large solar farm."

The cloud-based platform also developed by Ecoppia allows robots to be remotely managed at any global location. The company is able to integrate additional tools into the software to improve performance, such as weather forecasts.

"Generally speaking the artificial intelligence technology we have developed is able to exploit links between seasonality, geography and weather to optimise cleaning," she says.

Future developments and technologies

In the nearer term, robotics cleaning systems, such as Ecoppia's, will open up more demand as costs for the robots come down and the technology becomes smarter to deploy.

"Today we are seeing automated cleaning solutions that are deploying 'big data' and analytics, feeding in weather forecasts to optimise cleaning and tell the robots to stow themselves in strong winds, for example. But as robotic cleaning becomes more widespread, these machines could also be deployed in future to detect issues with panels, such as microcracks, as they pass over them, providing other types of maintenance functionality at the individual panel level on a near-daily basis," Strøm envisages.

Advances in unmanned aerial vehicles (UAVs), combined with software engineering and artificial intelligence are enabling automated cleaning of structures by drones. Aerial Power, headquartered in the UK, is one such start-up. The company's proprietary technology uses the drone's airflow to generate thrust but also blow sand and dust away from the panel surface. The drone uses sensors to detect the panel's or row's geometrical characteristics and aligns the UAV for cleaning.

One of the benefits of this approach means no loads are applied that creates pressure on the panel surface.

Prototypes have been tested in various locations since 2014, including panels in Chile's Atacama desert and at a site in Rajasthan in India.

Since patenting its concept Aerial Power has offered to license it to various utilities and other owners of solar assets in regions of the world with dry, dusty climates where wet cleaning is not feasible.

Company founder Ridha Azaiz says: "Generally these companies are interested, as they believe it can overcome shortfalls of other automated solar clean systems that they have tried using." But he thinks it will be another two years before his company's technology is commercially ready for solar panel cleaning.

"We've been using feedback to further refine the system with the view to developing a second-generation version and we are seeking solar supply chain partners and investors to work with in order to commercialise the technology.

An alternative anti-soiling approach which is still largely in development is the use of electrostatic fields for repelling the soiling from PV modules. Transparent electrodynamic screens or dust shields repel dust particles by creating a dynamic field over a surface. However, while lab demonstrations have proved successful, transferring the technology to the field has proved challenging.

Conclusion

In the coming years, robotics cleaning will become more mainstream. Strøm says, "It is already happening, but wider adoption will be driven by the reduction in cost of robots as volumes increase and the technology continues to improve in performance. As it becomes more proven, it therefore becomes more bankable."

Another trend driving uptake of automated cleaning, Strøm and Korevaar agree, is the trend to competitive auctions, happening all over the world, from Spain to Chile. This has increased the importance of de-risking all aspects of projects, including O&M. ■

Setting the standards

As capital costs for solar have come down, operational expenditure has increased as a proportion of solar's overall levelised cost of energy. As a result, the industry is focusing more on approaches and technologies that optimise operations – maximising output but also minimising O&M costs.

"In this regard, the need for independent standards for verifying the automated cleaning solutions available will become more important," says Scatec Solar senior vice president for O&M Pål Strøm.

Efforts are underway to bring a greater level of certainty to commercial decisions on the best technologies and approaches to cleaning. Among these, testing and certification house PI Berlin has been working on a standardised testing procedure for PV module cleaning products, to enable owners of utility-scale and multi-MW PV plants and installations compare different cleaning systems.

"We want to have a baseline which the PV plant operator, or procurer of the cleaning system, can use as a benchmark to decide which solution to invest in or purchase. It also allows the provider of a cleaning system or product to see how the cleaning method could impact the module glass," says PI Berlin marketing manager Benjamin Lippke.

PI Berlin's customers are typically the owners of large PV power plants and the manufacturers of cleaning systems. "A classic example is: the operator of the PV plant wants to acquire a cleaning system and needs to evaluate it. Approval is required from the module producer that the cleaning system doesn't damage the modules and therefore void the warranty."

PI Berlin's approach is to look at the real-life conditions at the location of the plant in question. "That means identifying to type of soiling and the properties of the soiling," Lippke says. "We work together with a sand supplier which provides us with test sand from the region in question."

The testing sequence itself contains several elements that together show how different cleaning methods can impact the anti-reflective coating of PV modules: visual inspection and qualitative reflection evaluation, reflection measurement, power measurement at standard test conditions (STC) and electroluminescence (EL) images. Lippke says that on their own, power measurements would be insufficient to reveal the consequences of any cleaning-related damage to the module coating over time; the reflection inspection and measurement provide a more visual representation of any coating degradation and any evidence of issues such as tire tracks. The further use of EL images helps reveal any internal damage such as micro-cracks, although Lippke acknowledges that as most cleaning systems run on module frames, they are unlikely to be the cause of such damage if it is found.

Lippke says there is also a case for providing standardisation around brushes and cleaning fabrics. "It would be nice to have a variable less to worry about," he says. Further standardisation around these enhance the evaluation process for assessing different cleaning products and solutions, especially when used with other criteria such as data on the type of soiling.

Credit: PI Berlin

Standardised testing procedures are helping shed light on the impact of cleaning technologies on module performance

Qatar solar research and testing facility 'open for business'

How do desert conditions affect performance and reliability of PV modules? What steps can be taken to maximize their energy yield in extreme heat and dust, combined with salinity and humidity? These are some of the key issues that Qatar Environment & Energy Research Institute (QEERI) is focusing on, as it ramps up its collaboration with solar companies worldwide.

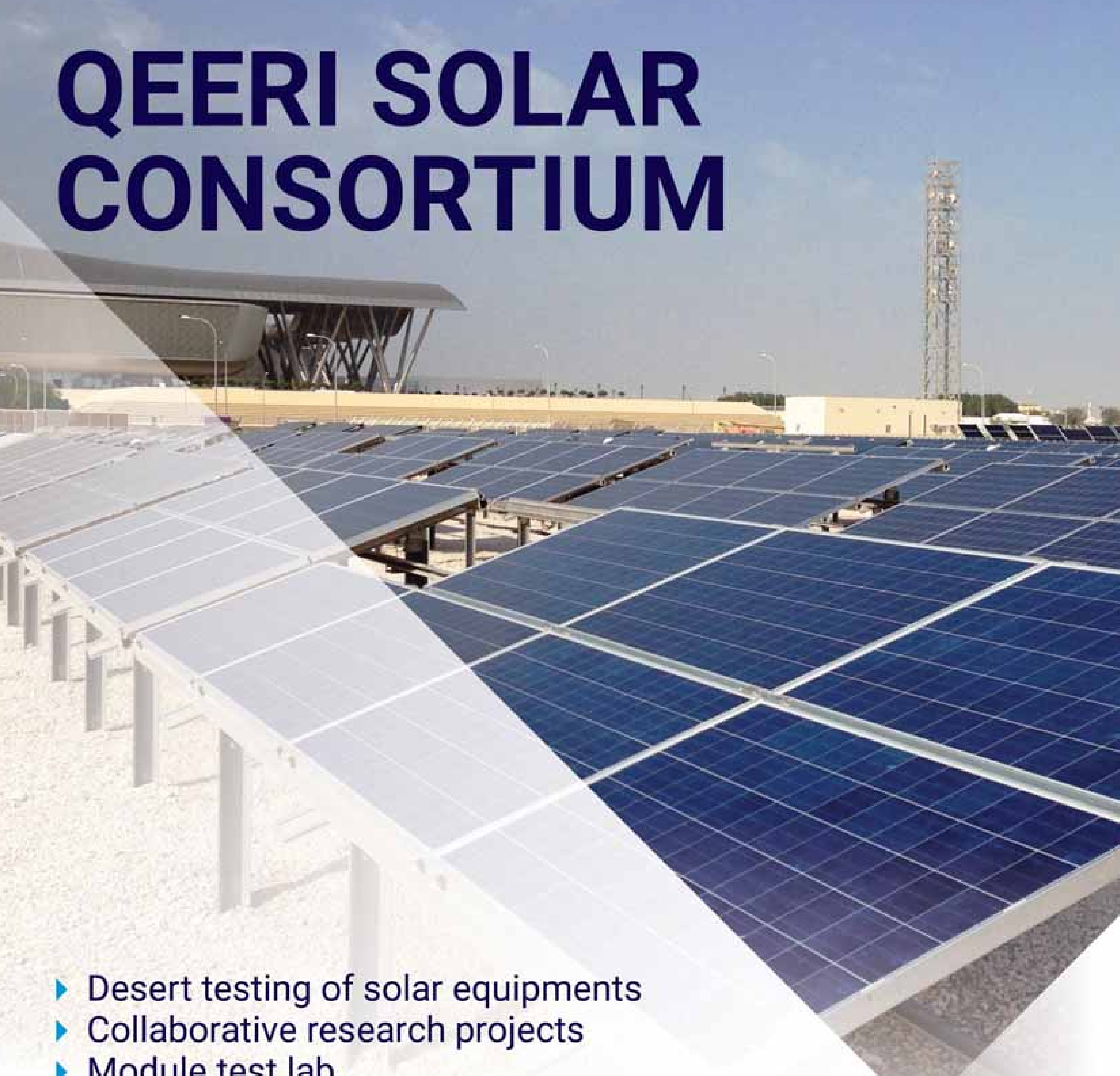
QEERI is a research, development and innovation Institute in Doha. It has long been a top destination for solar desert testing—since its Outdoor Test Facility opened in 2013, it has tested over 30 PV technologies from different manufacturers. It's the perfect environment for field testing, with severe temperatures, humidity and soiling. Recently, QEERI moved into its new home, a dedicated research building with state-of-the-art materials and testing labs.

With this investment in capabilities, QEERI is now ramping up its partnerships with companies in the solar, water, and environmental sectors. Last year it launched the Solar Consortium, a platform for solar research and testing, whose members include DSM, Hanwha Q-Cells, Nice Solar and Total, as well the local electricity authority Kahramaa.

Dr. Veronica Bermudez, QEERI's Senior Research Director of the Energy Center, explains: "From my background in the thin-film PV industry I saw how important reliability and operating conditions are and the advantages and opportunities these weather conditions offer to the renewable energy community. So that's where QEERI is focusing a lot of its efforts. At the same time, we are moving to work more closely with industry. This is how we will have the biggest impact and benefit to local solar projects, like the coming 350 MW PV plant."

The QEERI Solar Consortium has two parts: Member companies can test their technology at QEERI's outdoor and indoor facilities, while retaining full confidentiality and ownership of the test data. The other part is group research projects, where all members combine forces to tackle topics of common interest. The first group project, a study of PV coating abrasion in real-world cleaning conditions, starts later this year.

Dr. Bermudez continued: "We designed the Solar Consortium to be an attractive platform for international companies and local authorities to work with us on key issues— reliability, aging, and monitoring in harsh climates. We are really pleased with the start we've made and the great partners who have joined. Now we want to keep growing. Companies will find there is no better place for desert testing than Qatar."



Turning to the sun

Credit: Scatec Solar

Middle East | Simple economics are starting to overcome a reluctance to consider renewable energy in a region dominated for decades by powerful fossil fuel interests. Catherine Early reports

"When I first came to this region in 2007, solar wasn't talked about by the media and everyday people. Twelve years later, it is being talked about everywhere," reflects Gurmeet Kaur, board member of the Middle East Solar Industry Association (MESIA).

Targets for renewable energy and solar PV have proliferated across the region in recent years. Saudi Arabia is aiming to have 9.5GW of clean energy by 2023, Egypt wants 40% of its total electricity to be sourced from renewable energy by 2035, while Jordan has a goal of 10% of clean energy by 2020 and Morocco has ambitions for 5GW solar by 2030.

The United Arab Emirates (UAE) is targeting 50% of electricity from clean energy by 2050. Bahrain, Kuwait, Tunisia and Oman also have renewable energy targets.

Countries including UAE and Saudi Arabia followed the lead of trailblazers Jordan and Egypt, using competitive tenders similar to those they had used in the power and water sectors, which were already familiar to developers.

The turning point in seeing solar as an affordable source of power came in 2012, when Dubai's first tender for independent power producers (IPPs) for 200MW of the Mohammed bin Rashid Al Maktoum solar park achieved the lowest price globally for solar PV, at US$0.06/KWh, Kaur says.

"The really low pricing spiked interest in neighbouring countries. Solar is now cheaper than fossil fuels, which is what has driven the market in this part of the world," she says.

This has led to a change in attitudes in the region, which has for decades been dominated by cheap oil and gas. "In many oil-based economies that use oil domestically as well as for export, there's an increasingly strong value proposition for solar, as oil prices become more and more volatile. There's a lot of talk around economic diversification for countries dependent on petrodollars," says Benjamin Attia, senior analyst from the solar team at energy research and consultancy Wood Mackenzie.

The Middle East does not have the same constraints facing other solar markets, such as congested grid or land issues, or low sunshine, he notes. "I think the economic case far outweighs any sort of political constraints, which are fairly minimal at this point too," he says.

Though starting from a low base, growth is accelerating fast, with the

Megaprojects such as the recently completed Benban solar park in Egypt have helped put solar firmly on the map in the MENA region

region's strong solar resource boosted by ever-lower prices achieved at government tenders. The International Energy Agency's (IEA) latest renewable energy market update, published in October, revised up many of its predictions for MENA countries, mostly due to strong performance in solar markets over the past year.

"While the actual generation costs for each technology is country-specific, solar PV is increasingly seen as a cost-effective way of meeting fast-growing domestic power demand," says IEA renewable energy analyst Yasmina Abdelilah.

For example, the IEA forecast that renewable energy capacity in the United Arab Emirates (UAE) will increase by more than 6.3GW – a tenfold rise – almost entirely from solar PV and concentrated solar power (CSP). This is a significant rise from its forecast a year earlier, the IEA said, mostly due to new plans announced in 2018 by the emirates of Dubai, Abu Dhabi, Umm Al Quwain and Ras Al Khaimah for a competitive tender for 3.7GW of utility-scale PV.

Similarly in Morocco, the IEA's forecasts have risen to reflect the increasing economic attractiveness of solar PV and CSP, a more optimistic forecast for distributed PV, and a faster auction pace, with a tender for 230MW of combined solar PV and CSP projects announced in July, which the agency had not foreseen in its previous forecast.

The IEA also highlights the high growth potential of solar PV in Saudi Arabia, which has experienced "unprecedentedly swift progress" since targets for 2023 were increased three-fold, and new plans to tender 2.2GW were announced in January 2019.

The country's first tender saw 300MW contracted by Saudi developer ACWA Power, which achieved one of the lowest-ever solar tariffs of US$0.0234/kWh. The energy from the US$300 million is being bought by the Saudi Power Procurement Company (SPPC). The project was connected to the grid in November, and should be fully online soon, according to Attia.

"The first round set a precedent. There's obviously things that need to change, but the targets are aggressive and very realistic. There's been a lot of interest in the second round, with a large number of companies are pre-qualified to bid," he says.

Visible from space

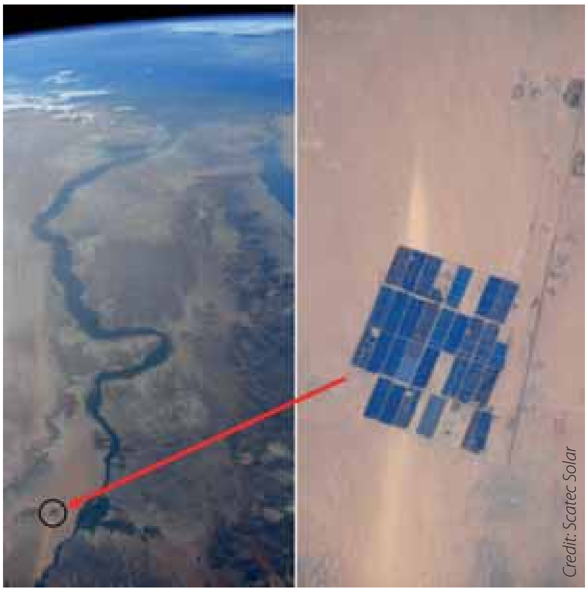
Over in Egypt, another MENA megaproject is now near completion. The 1.8GW Benban solar park is so big that its 7.2 million photovoltaic panels are visible from space. Egypt's first utility-scale solar PV project uses a multi-developer model, which has involved the government assigning plots to some 30 developers that expressed interest in the project, including Alcazar Energy, IB Vogt and Scatec Solar.

It attracted more than US$1.8 billion in public financing from at least 19 development finance institutions led by the European Bank for Reconstruction and Development.

The developer behind the largest section of the Benban project was Norwegian Scatec Solar. Morten Langsholdt, senior vice president of business development, led construction of the project. The government's 25-year feed-in-tariff was a strong incentive for developers to move into Egypt, where there was no track record for solar PV, he says.

The project was a good example of the public and private sectors working together to overcome challenges, such as acquiring the permits needed not only to construct the plant, but also to sell the electricity to a public utility, he adds.

The Egyptian authorities set up the New and Renewable Energy Authority to act as a one-stop shop to set up new procedures for the plant. "Everyone was quite pleased with the approach of the Egyptian authorities and their ability to make agencies and ministries across the public sector work together to find solutions so that these projects can be realised. It sounds boring, but it's very important when you're investing US$450million," Langsholdt says.


Credit: Scatec Solar

Egypt's Benban solar plant is so large it is visible from space

The plant was also notable for being the largest to date to use bifacial panels, which increase energy generation by around 15-25%. The technology is fairly new to the industry, but had never been seen before in MENA, meaning that it was perceived as slightly risky by some financiers. Following extensive discussions with investors, reasonable estimates of the extra energy generation were drawn up, Langsholdt reports.

"Now we have set a precedent for large-scale application of this technology, and everyone will receive informed estimates on the basis of our data," he says.

Not to be outdone, UAE also has very large projects underway. The Mohammed Bin Rashid Al Maktoum solar park in Dubai, led by utility the Dubai Electricity and Water Authority (DEWA), is now entering its fifth phase. The US$13.6 billion project is the largest single-site solar energy project in the world, with a planned total production capacity of 5GW by 2030.

It was announced in 2012, with the first 13MW phase coming online in 2013. Subsequent phases became gradually bigger, and the third phase of the project is now being built out, with 200MW of the total 800MW already complete.

Prices secured by developers on the project have continued to smash records, with US$0.056/kWh for the second phase, and $US0.029/kWh for the third phase. The 950MW fourth phase comprises a parabolic basin technology and CSP as well as PV, and is being developed by an international consortium for US$0.073/kWh for the CSP element, and $US0.024/kWh for the PV section.

The 900MW fifth phase will use PV panels only. DEWA announced the tender in February, and reported that it attracted 60 requests for qualification from developers. In November, DEWA confirmed that Saudi developer ACWA power had won the 25-year power purchase agreement at a price of US$0.01695/kWh – a global record for a solar PV IPP project.

Attia says it is not surprising to see such low bids on a large-scale tender in a stable, attractive policy and regulatory environment, where there was also a strong procurement track record, transparent tendering, access to cheap finance, land allocation and easy interconnection and synchronisation within the solar park. "The ingredients are all there for very low prices," he says.

Abu Dhabi meanwhile has this year seen completion of 1.18GW Noor solar PV plant at Sweihan, jointly developed by Japan's Marubeni Corp and utility the Emirates Water and Electricity Company (EWEC), with panels by JinkoSolar. The project was contracted at US$0.024 cents per kilowatt hour.

EWEC now has plans for a 2GW project at Al Dhafra, which will take the emirate's total solar capacity to 3.2GW. In July, the utility reportedly shortlisted 24 out of 48 international and local developers expressing an interest bidding for contracts.

The plant is expected to be operational during the first quarter of 2022, meaning that the tender results should be announced before the end of Q1 2020, Attia says. "Similar to DEWA's recent results, and the Sweihan tariffs, I'd expect financial bids will be globally competitive at Al Dhafra as well," he adds.

Prices still falling

Successive tenders such as these have seen price records continue to be broken in the region, but commentators believe that the floor has not yet been reached. "Everyone has said that the prices can't keep dropping, but I'm not sure we're at the point where they can't go lower yet," says Kaur.

Once use of storage alongside solar PV becomes common, costs will sink even lower, making solar truly a replacement for fossil fuel plants in the region, she says. The

Commercial and industrial rooftop sector takes off

Many experts in the MENA region are touting the huge potential for distributed solar generation from commercial and industrial premises. An initiative in Dubai has demonstrated the opportunities in this sector, if appropriate policies are put in place.

The Shams Dubai project has been led by the Dubai Electricity and Water Authority (DEWA) since 2015, in an effort to encourage its customers to install solar PV panels on the rooftops of their offices, factories and commercial premises. Participants can both generate electricity from solar power, and export the excess to the power grid. The value of the exported electricity is then deducted from the company's future utility bills.

Some 1,354 buildings in the city, totalling 125MW of power, have now been connected via the scheme. DEWA has installed several distributed solar projects at its own premises, including the 1.5MW plant at Jebel Ali Power station.

The initiative's first business customer was the city's Al Maktoum International Airport, with a capacity of 30kW, followed by other private sector participants including the Emirates Engine Maintenance Centre in Warsan, where a 1MW installation on a carport was installed. Some 19 government organisations have also installed PV panels.

DEWA has also backed up the policy with a calculator to help property owners estimate the potential income from solar panels on their rooftops and certified consultants and contractors to plan and carry out installations. It runs its own equipment eligibility scheme and training programmes to improve confidence in the technology, and skills in the sector.

One PV company participating in the scheme is Yellow Door Energy, which has installed more than 100MW on commercial and industrial rooftops in Dubai. It develops and leases the PV panels and other equipment, acting as long-term investor and owner of assets. The company's chief executive, Jeremy Crane, says that customers range from food and beverage, retail, and light and heavy manufacturing.

"We believe that there's a potential in Dubai for 400-500MW in the next 10 years, probably at a rate of around 50-60MW per year. Projections from the government are higher – more than 100MW a year," Crane says.

Crane does not put this down to any particular problem with the scheme, just that the assumptions on the rates of uptake were too optimistic, and that businesses take a while to adopt new ideas for long-term investments.

Crane believes that most of the demand for rooftop solar will come from large international corporates, such as Unilever and Nestle, who have carbon reduction commitments and as such, are motivated to use renewable energy.

Although other countries in the MENA region have considered similar models to the Shams Dubai initiative, adoption is extremely slow due to the very low cost of power for commercial and industrial customers, he says.

Others agree that government subsidies for energy are hampering the growth of distributed solar in the region. The International Energy Agency's (IEA) report on renewables in October states that if retail prices for commercial and industrial players in UAE became cost-reflective, distributed PV would double its rate of expansion.

However, in Egypt, power subsides for this sector are being discontinued, the report noted. Together with the introduction of net metering and falling system costs, self-generation has become increasingly economically attractive to businesses, and doubled the capacity of distributed solar PV, it said.

Credit: Yellow Door Energy

Distributed solar in the MENA region has had some success, such as in Dubai, but been constrained by the low cost of power for C&I customers

burgeoning use of bifacial modules will also make a difference. Previously, tendering documents prohibited the technology as there was no knowledge or history on performance, she explains. "I think in the future, we'll see a relaxation of tendering rules to enable more cost-effective and efficient products to be used," she says.

Attia believes that some countries could be approaching an artificial price floor for solar PV projects. But he agrees that tender requirements in the region could be tweaked to include other criteria. "We may start to see projects required to include storage, or other types of evolution where criteria besides just large generation with a low tariff are valued," he says, citing examples such as generation at different time blocks during the day, seasonal tariffs, or specific power production requirements for non-utility offtakers such as gasfields or desalination plants.

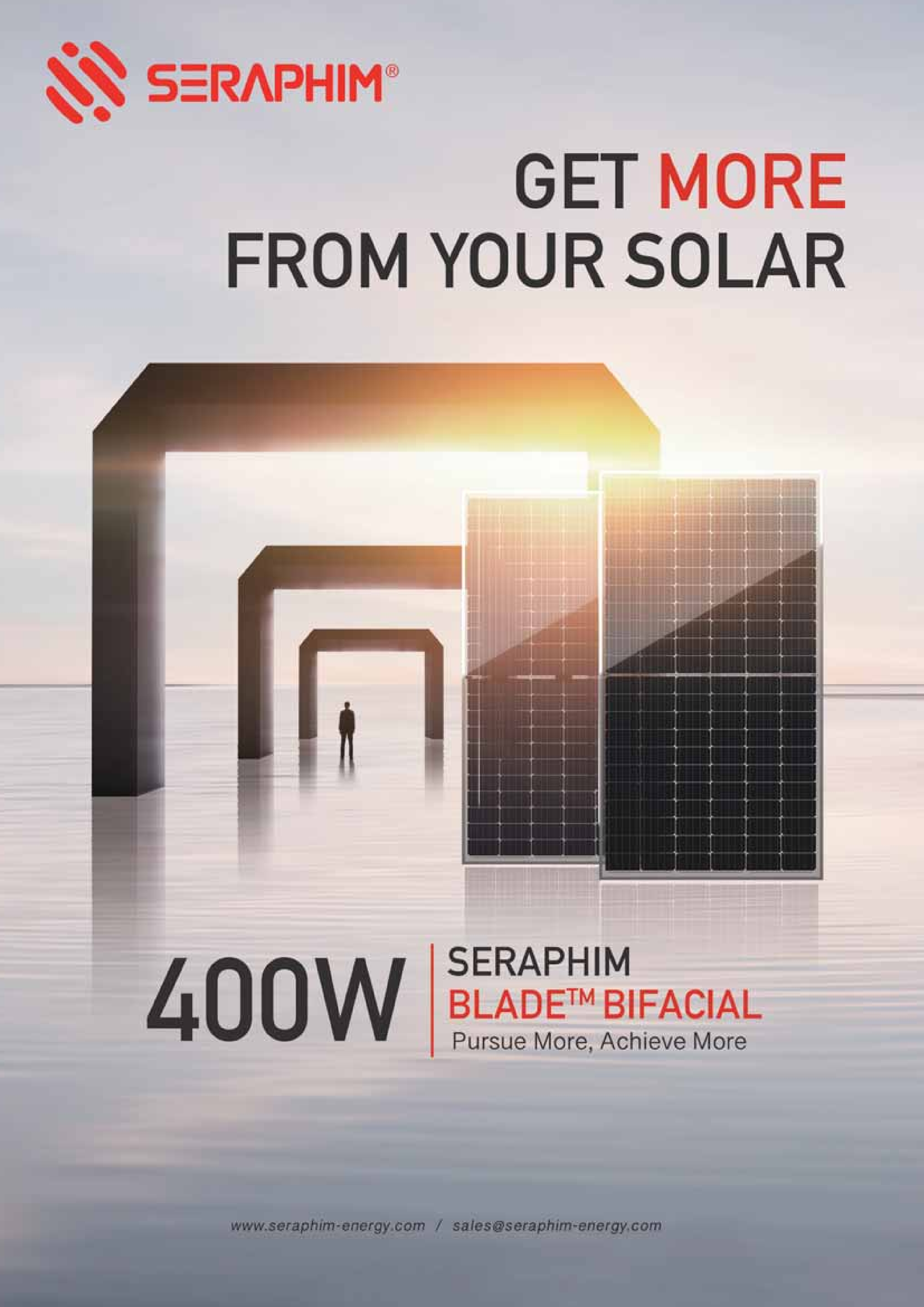
Experts in the region see that growth could yet be restrained due to a variety of factors. Balancing the grid access could become an issue, though not just yet, Attia believes. "There is a lot of talk around regional power trading, and connecting to Africa and Europe. But the market is not at the point right now where there is so much demand that we'll run into issues around balancing the grid due to high penetration of renewable energy," he says.

Abdelilah believes that the pace of growth could be accelerated if countries published schedules setting out a timeline for auctions on the way to meeting their renewable energy goals, most of which target 2025 or 2030. "That would give more visibility to banks and investors – if they know a country is tendering a certain amount each year, it's easier for them to give financing for both large-scale and small-scale PV. It sends a lot of signals to all stakeholders in the region that would bring costs down," she says.

Overall however, the outlook is very positive, she says. "We've updated the forecast for the second year in a row because things are progressing faster than we had previously thought. Governments are not shying away at all from renewable energy, more the opposite.

"Oman has jumped on the bandwagon this year and opened a tender. It used to just be Morocco – now everyone is heading towards a cost-competitive source of energy, and that is solar PV," she says. ■

For more on the Middle East's adoption of bifacial solar technology, turn to p.50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Risky business

Policy | Despite several years of incredible momentum in the Australian solar market, energy policy wars raging in Canberra are prompting investors to take pause. What does the election of Prime Minister Scott Morrison – who famously brandished a lump of coal in parliament to show his support – and a federal renewables policy void mean for the industry? Cecilia Keating reports

In early September, Australia's Clean Market Operator announced that the 33TWh large-scale renewable energy target (RET) had been met.

Federal energy and emissions reduction minister Angus Taylor marshalled the milestone to tout Australia's credentials as a world leader in clean energy investment, claiming that "with the RET set to be exceeded, investment is not slowing down".

The figures tell a different story. According to the Clean Energy Council (CEC), clean energy investment in the first half of 2019 dropped to levels not witnessed since the RET was threatened by federal politics in 2015. Average quarterly investment in new generation capacity dropped to 500MW per quarter in 2019, from more than 1,600MW per quarter in 2018.

Despite the peachy economics of solar down under, industry stakeholders say that uncertainty and volatility bred from a lack of federal policy, under-investment in the transmission network and the continued deployment of the marginal loss factor (MLF) pricing regime, is prompting investment to leave Australia.

What's next after the RET?

Despite being a prospective home to some of the world's most ambitious PV and hybrid projects – including a 10GW solar-plus-storage farm in Northern Territory that will shuttle energy to Singapore, a 4GW wind-solar-battery hybrid in New South Wales (NSW) and a 15GW wind and solar hub in West Australia – investment in large-scale renewables projects is waning.

The now-satiated federal renewable energy target (RET) has long been the only federal mechanism incentivising large-scale renewables. Since 2011, renewables generators have been issued with certificates (LGCs) that could be sold and traded to offset development costs. Utilities and other high energy users are required to acquire LGCs by law.

Credit: AGL Energy

Now that the country has collectively installed 33TWh of renewables, high energy users will no longer be bound to purchasing LGCs. Australia, like China and the US, has not committed to a clean energy target, beyond its commitment to the Paris Agreement.

"The challenge for investors though is having long-term confidence in the energy market and particularly the revenue they might receive for it," Kane Thornton, chief executive officer of the CEC explains. "And at the moment, rather than have a policy, particularly one that gives them certainty around the levels of emissions in the energy sector expected or indeed the phase out of coal over time, there's a lot of uncertainty."

The CEC forecasts that investment will continue to sputter without a replacement for the renewable energy target. This could take the shape of a carbon tax, resuscitating the abandoned national energy guarantee, an extended RET, or a clean energy target.

"Investment is not going to fold to zero. We will see projects still go ahead. Australia is a good place to invest, we've got great renewable resources. In the long term, people can see that the economics of renewables are strong. But in the short and medium term, it's really hard to predict," he says.

Policy uncertainty has cast a shadow over Australia's hitherto flourishing solar market, dampening investor interest

The economics of solar in Australia are indeed robust. A report published in December 2018 by the nation's leading scientific research group, CSIRO and Australia's Energy Market Operator (AEMO) showed that the levelised cost of electricity (LCOE) of solar and wind when paired with two to six hours of storage is lower than any other energy resource.

"Investment is not going to fold to zero. In the long term, people can see that the economics of renewables are strong. But in the short and medium term, it's really hard to predict"

But it's a case of needing certainty and stability, according to Thornton. Investors need to be able to plan around

the retirement timeline of the 14GW of coal-fired generation expected to come offline by 2040.

"We've had a decade of really silly politics on climate and energy policy, it's been problematic and challenging. We've wasted that decade arguing whether climate change is real or not instead of developing a really clear strategy and managing the transition," Thornton says.

Ongoing government investigations into the potential of nuclear power deployment and whether to extend the 2GW Liddell coal plant's life in NSW (potentially using taxpayer money) has sent a clear signal to industry that timelines could be unreliable.

Carlo Frigerio, managing director for developer FRV Australia, says solar investors need "clear and well-coordinated policy at the federal level", adding that a number of FRV's competitors were "becoming more and more concerned about the policy climate".

Madrid-headquartered FRV was "one of the first international solar developers to bet on Australia," he said, and has invested about US$700 million in the country since 2010. It has two contracted projects under construction and four operational PV projects, including two 100MWac plants in Queensland.

"Our ability to predict the energy markets, and in particular electricity prices, are of course fundamental to our investment decisions," Frigerio says. "Trying to read how energy markets will react to the energy transition, to the replacement of coal with dispatchable generation, and to the development of storage systems, paired with the uncertainty of a non-existent federal policy is making it very difficult for any operator to make those assessments."

Adam Pegg, Australia country manager for Lightsource BP, says that the RET had "done a good job in promoting emerging technologies such as solar" given that the developer now competes on "an energy-only and unsubsidised basis".

"All we ask for now from the government is a level playing field. So, we don't want to see subsidies going towards fossil fuels," he says. "We want to see the government supporting investment into the network. And to make sure that we can make our carbon target that we've committed to under the Paris Agreement."

The British developer has a 1GW pipeline in Australia and recently reached financial close for a 200MW farm in NSW.

It won the project in a tender floated by state utility Snowy Hydro that reportedly attracted rates of between AU$40/MWh and AU$50/MWh (US$27/MWh and US$33/MWh), according to Renew Economy.

Corporate Australia leading policy makers

Matt Stocks, an energy integration and renewables researcher at the University of Australia (UoA), notes that that the over-subscription of the renewable energy target did not render LGCs valueless.

"The legislation continues; the certificates will still be generated. Developers still get a certificate for every MWh they produce. The challenge now is, what value do they now have?" he said. "It might be that they have value in Australia, either as corporates start to look at them and are willing to step into the climate change space and say, 'I'm doing the right thing', or there may be other mechanisms working around that."

He notes that ideological wars in Canberra rage independently from a growing public appetite for renewables: "It's a political challenge, not a public acceptance challenge. There is an opportunity if the right combination of things come together for Australia to continue to accelerate ahead. I don't think it's all as doom and gloom."

An Australian Institute survey of nearly 2,000 Australians in mid-2019 showed that 69% of Australians supported government incentives for renewable energy and 76% ranked solar in their top three energy sources.

Corporations in Australia are increasingly turning to procuring energy to bypass volatile energy markets and to appeal to public sentiment. Energy consultancy Energetics says nearly 4,200MW of clean energy has been supported by corporate PPAs since 2016 in Australia. More than half of total project capacity supported was solar.

In the latter half of 2019, a group of high energy users that included universities and businesses in Melbourne put out a tender for more than 113GWh annually. Mining giant Molycop signed a 100GWh-a-year deal, with Flow Power and Coles Supermarkets signed a 10-year deal with Metka EGN for power from three under-construction solar facilities in New South Wales.

"Corporates are leading the policy makers in terms of procuring clean energy," says Lightsource BP's Pegg. "So, despite the uncertainty in policy, the market is moving in that direction over the medium to longer term anyway. We're just getting on with business and we see overwhelming support from corporate Australia to move in that direction. And they are customers we will be looking to contract with," he said.

Energetics expects total corporate renewables PPAs to reach 1,000MW in 2019, a drop from 1,800MW for the full year of 2018. Associate Anita Stadler says that the slow-down "was not unexpected", with the cost of LGCs falling and the corporate PPA market being more established.

In July – when only 200MW of deals had been clinched – Stadler pinned the dip on the May federal election and changes to AEMO's transmission loss costing regime.

The position of Australia's federal government under prime minister Scott Morrison, right, on renewable energy appears at odds with public appetite

Credit: G20 Argentina, Flickr

State of play

Incentives for renewables now lie on the shoulders Australia's states and territories, and the majority have implemented ambitious climate targets.

The states of Victoria and Queensland are eyeing 50% renewables by 2030; South Australia (SA) and Tasmania's targets are even higher, at 75% and 80% respectively. The Australian Capital Territory (ACT) completed contracts for 100% renewable energy by 2020 in October – the first jurisdiction of more than 100,000 people outside of Europe to do so. Reverse auctions have been held in ACT and Victoria.

According to the Smart Energy Council's (SEC) chief executive John Grimes, the disconnect between state and federal policy comes down to remit.

"When you as a government are responsible for the energy, providing energy, and you take the political heat about the cost of that energy, then everyone gets pretty pragmatic and economics-driven. Which means, they basically support renewables," he says.

"The federal government's a bit more distant from it, and so they're not directly responsible so they kind of have the luxury of being a bit more ideological rather than pragmatic."

Transmission trouble

Federal policy void is only one part of the reason why investment in Australia is risky. Grid connection and transmission issues, alongside a suite of unpopular reforms proposed by Australia's independent market bodies, are also prompting investors to look elsewhere.

AEMO has acknowledged an urgent need for more spending on transmission infrastructure to ease grid bottlenecks caused by an arsenal of new solar and wind generators.

Leonard Quong, head of Australian research at Bloomberg NEF, estimated in early November that there were currently "more than 50" rule change requests for market and transmission and integration regulation reform.

He says contention between independent government bodies and different industry players over the responsibility and process for reforms coalesces with federal and state policy rifts to breed more volatility and uncertainty for renewables investors.

FRV's Frigerio notes that connection approval takes twice the amount of time today than it did in the past. "There has been an increasingly conservative approach from AEMO and from the TNSP (transmission network service provider). There's more scrutiny, more reviews and ultimately more costly development delays."

The SEC's Grimes says the government is resorting to an "ostrich-like approach, where you bury your head in the sand, rather than fight realities" to the country's transmission troubles.

"Decisions are not being made about investing in transmission and distribution infrastructure that's going to facilitate new renewables coming online. Instead they come into existing lines that are really crowded," he explains.

Grimes likened the situation to attempting to swap from driving an internal combustion vehicle to an electric vehicle – without stepping out of the car.

"We're going from a fossil fuel-generated, hierarchical, one-directional, inflexible energy system to an integrated, distributed, renewable, variable energy system. And we're doing it without having a transition plan in place," he says.

"That's actually really, really dumb economically because it means that the transition is not as economically efficient as it ought to be. It's a game that we are playing, and the efficiency and the competitiveness of the Australian economy is what is ultimately at stake."

Ongoing transmission reform proposals, the "Coordination of generation and transmission investment" (COGATI), crafted by the Australian Energy Market Commission (AEMC), have been slammed by the SEC as a "tax on renewables paid to fossil fuels" and an attempt to ration transmission instead of expand it.

Jonathan Upson, director of origination at Canadian Solar, delivered a scathing verdict of COGATI in a letter to the AEMC, saying that it will lead "to a massive drop in new generator investment. Our confidence is based on our witnessing this decline today caused by just the possibility that COGATI may be implemented (…) Surely, it is self-evident that if anything close to 90% of the stakeholders *who are to be the supposed beneficiaries of a reform* oppose it; it's time to Stop [sic]."

COGATI is a series of rule changes set to come into effect in July 2022 that will create a market for generation hedges and aim to encourage developers to build in locations that are most profitable. State energy ministers rejected the proposals at a meeting in November.

One of the most controversial segments of COGATI is the marginal loss factor (MLFs) regime, the method used for calculating and charging energy generators for energy transmission and network losses.

Because MLFs are not a tradeable market, developers can't hedge against them, unlike in nodal markets. If a developer establishes a plant in a good location, every rival who follows suit undermines its MLF. MLFs are published each year in the spring and come into force in July.

In a decision in mid-November, AEMC decided to keep the MLF system more or less intact after a rule change request, albeit committing to making the calculation system more transparent.

"Rather than penalising generators located in strong parts of the network, or consumers, the underlying challenge is to better coordinate investment in generation and transmission across the national electricity market so that financial incentives … are aligned with the physical needs of the system and everyone can benefit," AEMC chair John Pierce explained in a statement.

But investors counter that energy ventures have faced year-on-year MLF rating swings of more than 20%, impacting revenues in unpredictable ways.

That's according to the Clean Energy Investor Group, a coalition that counts Macquarie Group, Innogy, Blackrock and Neoen among its members and represents AU$11billion of investment. The group issued a stark warning in September claiming lack of reform will cause private investment to leave Australia, ultimately increasing prices for the consumer.

Frigerio likens the MLFs to a black box. "There is no way to know what a MLF is going to be for the next five years or 10 years and it's becoming more and more complicated for developers and debt providers to form a solid view."

Despite the volatility, Australia's long-term solar future is bright, according to Quong.

"There's a lot of uncertainty, but in terms of how we think that's going to impact the investment or the story in solar and batteries, the story looks reasonably rosy, at least on an economic and fundamental level," he says.

"Solar in Australia is incredibly cheap and it's only going to get cheaper. And even with potentially a reasonable cost placed on those generators to integrate and balance the grid, they'll still remain very economically competitive as a new source of generation." ■

Australia's goes big on storage

Constraints in the grid mean that storage systems are more attractive than ever for balancing – and Australia has been proven as fertile ground for colossal energy storage systems.

The 129TWh Hornsdale battery system in SA – borne from a AU$50 million Twitter bet between Tesla's Elon Musk and Australian billionaire Mike Cannon-Brooks – is due to be expanded by Neoen, thanks to an AU$15 million (US $10.2 million) from the SA government, up to AU$50 million from the nation's Clean Energy Finance Corporation and AU$8 million from the Australian Renewable Energy Agency.

The latter outfit has played an important role in getting grid-scale energy storage projects off the ground, but is earmarked for retirement in 2021.

Batteries can't scale until market design is updated, according to the CEC's Thornton.

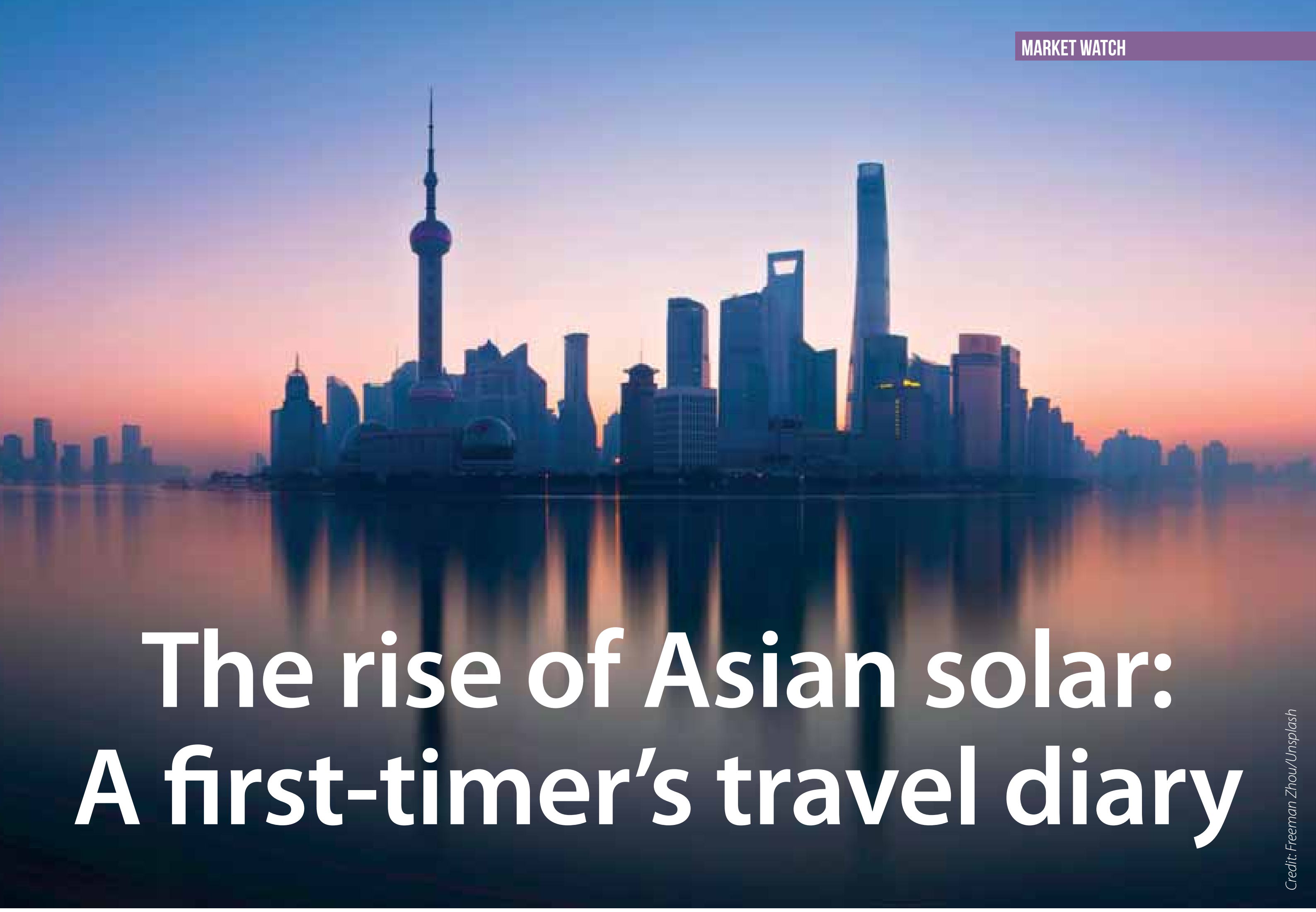
"We really don't have defined ancillary services," he explains. "And so even though from a system perspective, we need more energy storage, the sort of market design isn't necessarily there to provide a trust signal for new investors, particularly in energy storage."

"The big question on batteries right now, outside of how far in cost they are going to come down – because we know they will do, it's just at what point in time do they become competitive – it's a question of revenue certainty" says BNEF's Quong.

"People are used to signing long-term offtake agreements for large bulk supply of electricity. There is no option really right now for (battery) services. How does one structure a contract to peak capacity? How does one structure a contract for auxiliary services to balance the market? And even if there were contacts available, who pays for it and what's the price in the long term?" he explains.


Credit: David Clarke, Flickr

Australia is proving to be fertile ground to large storage systems such as the Hornsdale Power Reserve



Credit: Freeman Zhou/Unsplash

The rise of Asian solar: A first-timer's travel diary

Emerging solar | From China's bullish manufacturers to Malaysia's blossoming ecosystem and Taiwan's downstream ambitions, Asia has come to shape the fortunes of global solar. José Rojo charts the continent's dazzling ascent after visiting all three markets in late 2019

Any journalist taking on the solar PV beat in 2019's world would take very little time to spot the long shadow cast by Asia over the global ecosystem.

The continent's rising star is of course best epitomised by China, both the unassailable leader of all downstream solar markets and the upstream locomotive that keeps installations ticking across the globe, from Atacama to Nairobi, Warsaw or Melbourne. The spotlight is not, however, restricted to Beijing: from Vietnam's feed-in tariff (FiT) rush to Japan's steady growth, Taiwan's multi-gigawatt campaign or Malaysia's oversubscribed tenders, once-secondary markets are rising to the fore.

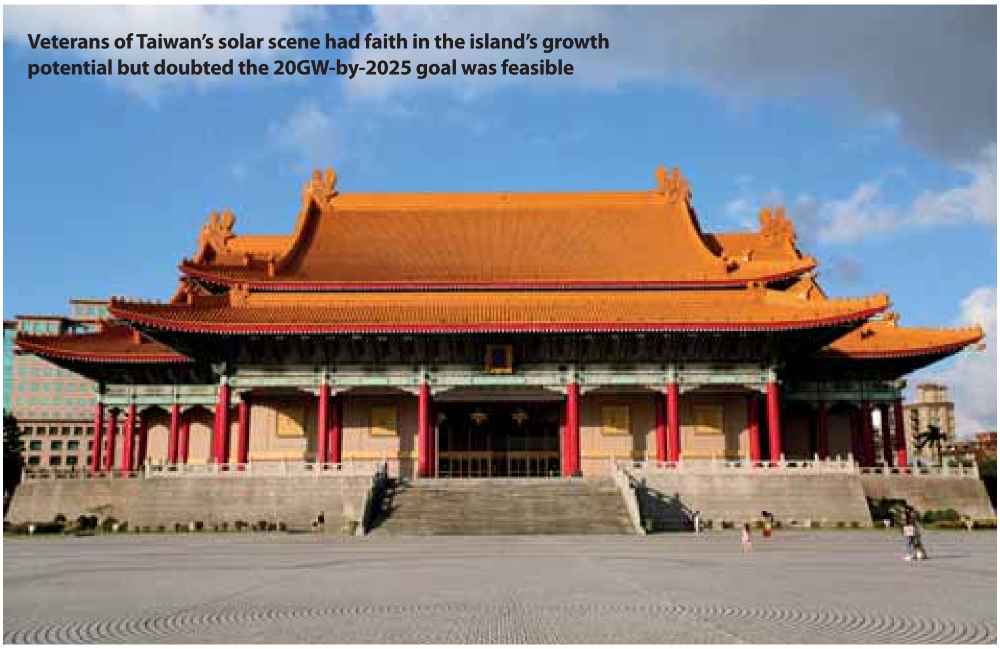
Taiwan, the first stop of this correspondent's Asian tour in late 2019, is emblematic of the region's many solar triumphs and trials ahead. Its very existence, with millions crammed into a slim strip of land encroached by geopolitical hostilities and natural hazards, is an act of defiance. As the plane takes one last, sweeping turn on the journey to Taoyuan airport, the island's mixed solar blessings are displayed in full view: blinding, bountiful sunlight that would be anyone's envy but also an intractable geography, the sort that forces site-seeking solar players to choose between steep forest valleys or overcrowded lowlands.

The contradiction between Taiwan's solar strengths and its structural weaknesses is apparent from the moment Energy Taiwan 2019 kicks off. Two discourses jostle for attention at the trade show in Taipei, attended by *PV Tech Power* on 16-18 October. There is the confidence of government officials taking the floor to talk up plans for installed PV capacity to hit 20GW by 2025 from about 3.4GW today. There is also, however, the more cautious mood of actual solar operators, who agree the goal is feasible but tend to doubt it can be achieved as quickly as top officials would want.

On one corner, the government offered grand statements about how Taiwan's bright solar future was inextricably linked to its supposed status as an industrial powerhouse. If Taiwanese PV is to triumph, president Tsai Ing-wen's message said as she gave her conference keynote speech, it is because the industry can tap into the island's pre-existing strengths as a global hub for manufacturing and electronics. Terry Tsao, president of semiconductor association SEMI Taiwan, struck a similar tone as he boasted of the island's "complete PV supply chain" as he spoke after the president.

Chinese PV makers may have wiped out rivals all over the globe but now face a game of musical chairs at home, with domestic roll-out tanking.

On the opposite corner, however, solar veterans poured cold water on the upbeat rhetoric with a simple question: can 20GW of PV be squeezed into a jam-packed island? Asked whether the goal is achievable by 2025, TATUNG Forever Energy project manager Max Lin countered with an emphatic "no", pointing at land scarcity and bureaucracy. By way of example, he spoke of his firm's 130MW utility-scale PV project, which cannot go forward until all 30 site owners agree and the central government gives the final



Veterans of Taiwan's solar scene had faith in the island's growth potential but doubted the 20GW-by-2025 goal was feasible

Credit: Sun De An/Unsplash

nod. "We've put so much money, people on the ground," Lin lamented. "This is a political issue."

Interviewees also regaled with tales of what deploying solar is like in the land of earthquakes and typhoons; a reality some in the knot of visiting journalists had already been introduced to the night before, after witnessing a magnitude 5.4 tremor that shook the entire island, capital Taipei included. O&M specialist JNV Solar Power, for one, described the taking out of full insurance packages for natural hazards as an absolute necessity in Taiwan. Other conference-goers rued the impact of low power prices on solar project economics, a circumstance some linked to government intervention

The winners and losers of Asia's upstream race

If Taiwan's downstream solar players are bracing for an uphill trek to mass-scale success, its manufacturers face a near-impossible rope climb against the dominance of mainland China. The island's collapse in recent years from global cradle of upstream solar to economic ruin – and the heavy human price the industry has paid in the process – was etched all over the words of Jenny Hsu, global sales manager of Motech Industries.

"We started 37 years ago and used to be very big, with 3GW in cell and wafer capacity. We used to be pioneers ... but we failed," said Hsu, with journalists hanging onto her every word as she charted Motech's descent from global top 10 rankings in 2016 to factory shutdowns and major layoffs in 2018. Last year, the New Taipei City-headquartered firm fired some 1,200 workers at one time as it shuttered a 1.1GW cell production line in Taoyuan, southern Taiwan. "Both for those who left and those who stayed, it was a very distressing time," Hsu recalled.

The chat with Hsu, arranged behind closed doors at Motech's Energy Taiwan 2019 stand, quickly moved towards how the firm was planning to bounce back. She spoke of a three-step recovery plan – HR engagement to ensure staff satisfaction, asset sales to shore up finances, R&D investment to regrow the manufacturing edge – and described Motech's efforts to diversify to downstream plays. Asked how other Taiwanese PV makers were adapting to low-priced Chinese rivals, Hsu felt some may have left it too late: "Adjusting was difficult for us but at least we got in at the right time."

Mainland China, a later leg of this correspondent's Asia visit in October 2019, may lie just a 180-kilometre strait away from Taiwan but the mood of its solar industry felt a world apart. Touring the skyscrapers of Shanghai's financial district and the buoyant PV factories of Hangzhou, Suzhou and others, the message could not have been clearer: this is a country where the makers still march, where a well-oiled government apparatus throws as much muscle and ruthless efficiency as it can muster behind the cause of economic boom.

For someone reporting on the comings and goings of global solar from London, it was refreshing to finally put a face on some of the firms supplying the entire ecosystem. At boardroom meetings – and PV manufacturing site tours, a first for this correspondent – the conversation was no longer about how a firm may stay afloat but rather how high it may soar on the wings of low prices. From gigawatt-scale module-making household names to smaller players still in the megawatt region, all in China seemed to be laser-focused on how much, and how fast, production and sales could grow.

And yet – for all the undeniable strength, the upbeat talk did not mask that the inwards competition can be just as brutal. Chinese solar makers may have wiped out rivals all over the globe but now face a game of musical chairs at home, with a once-inexhaustible domestic solar market slowly grinding to a halt. Still in Shanghai, this correspondent saw the release of official stats showing China had only installed 16GW of PV as of September 2019 – compared to 45GW over 2018 – coinciding with a clampdown on subsidies. As the taps dry at home, the scene is set for a Chinese stampede abroad.

Makers march overseas as roll-out falters home

Every Chinese manufacturer *PV Tech Power* met – and those this correspondent heard of besides – was well and truly immersed in the great rush overseas, with roadmaps meticulously laid out to ensure a competitive edge over rivals.

Dr. Liyou Yang, general manager of Jinergy, sounded bullish about his firm's odds of victory. Interviewed in downtown Shanghai, he struck a measured tone as he spelled out how the PV maker plans to boost cell and module production firepower from 2.2GW today to 4.5GW next year. The 2.3GW build-up will be mostly mono-PERC modules churned out by new factories, Yang told *PV Tech Power*. In a further sign of the overseas obsessions of Chinese makers today, he said the new module facilities may lie by seaports, to ensure easier exports than under the firm's current industrial base in the inland province of Shanxi.

Later in the chat, Yang's very own remarks suggested Jinergy's boss appreciates the paradox of doubling production output at a time of global solar module glut. Noting that the performance of module-buying solar players next year remains an unknown, he conceded: "Given the drastic cost decreases we've seen, particularly on the mono-PERC side, the key question for me is whether all this rapidly rising production capacity can be fully utilised." He remained adamant, however, that Jinergy would not struggle to find global markets for its very own "rapidly rising production capacity" of 4.5GW.

Asked to list the firm's top overseas targets, Yang said that India will be king; Jinergy's "very good reputation" after three years of brand building means it is well placed to service the next phase of growth, the general manager said. He also pointed at Europe – with Jinergy already supplying 100MW to Ukraine and also entering Germany and Spain – but added that China will remain a key destination, deployment slump or not. Jinergy's belief, Yang said, is that its focus on an area likely to stay strong on the solar front – its home in the Shanxi Province – will ensure continued strong sales.

The rewards but also the hardships of Chinese makers' overseas forays were unmistakeable in the words of Lin He, Latin America general manager of module manufacturer GCL-SI. The firm, which shipped 2.3GW in 2018, has specifically set sights on one of 2019's hottest solar markets: Brazil, where a mix of inherent solar strengths – high irradiation levels, a developed grid – and support from unlikely solar champion president Jair Bolsonaro is prompting a deluge of foreign interest.

Meeting *PV Tech Power* at GCL-SI's Suzhou headquarters, Lin He seemed vividly aware that his firm is far from alone in its appetite for Brazil. The talk revolved around how GCL-SI would outrun what Lin He described as the "10 or 20" low-priced Chinese module rivals also targeting the South American market. The firm's recipe included tailored service, expansion into the distributed segment and, chief of all, the PV technology that stole the spotlight in 2019. "Normally, our tier 2 rivals have no chance to supply bifacial," Lin He said, arguing that a focus on two-sided modules would help GCL-SI take shipments to Brazil from 260MW in 2018 to 500-600MW in 2020.

For manufacturer Hoymiles, a differentiated offering was also the ticket to overseas success. Giving *PV Tech Power* a tour of its assembly line, the Hangzhou-based firm spun a confident tale of how the supposed strengths of its microinverters – around 10-30% higher efficiency, fire-safer PV modules thanks to lower DC voltage – would allow it to double sales within a year. The firm, historically reliant on European rather than Asian buyers, shared plans to set up new bases in North America, Brazil and Australia. The globetrotting ambitions were reflected on the country-coded shelves where factory staff piled newly assembled microinverters later that day, at this publication looked on.

Relentless innovation

The packed travel schedule also left time to briefly step beyond the Chinese-speaking sphere, where a new solar era is dawning. Peering at Malaysia's Penang Island from the air, this correspondent found himself reflecting on Wood Mackenzie's predictions this year that renewables will outcompete coal across every single key Asia-Pacific market by 2027.

Some, as evidenced by the rush for Vietnam's FiTs or Malaysia's auctions, won't likely wait that long to witness a downstream solar surge. Upstream growth may, meanwhile, come via the Southeast Asian factory moves of Chinese PV makers keen to sidestep the US' anti-China sanctions; judging by the chat with Jinergy's Yang, the module maker is among those considering that very route.

Bridging the gap between both halves of the solar equation – manufacturers and developers – was PV ModuleTech 2019, held in Penang on 22-23 October and the reason this reporter was in town. The annual conference, arranged by *PV Tech Power*'s publisher Solar Media, assembled downstream and upstream players to discuss the challenge that affects both: the dizzying pace of module technology innovation. Experts took the floor to deconstruct, through hard numbers, the hype around bifacial and other disruptive solar technologies.

Many in the crowds filing into Penang's G-Hotel Gurney as monsoon clouds gathered outside had, however, one chief reason to attend other than general innovation talk. The result of five years' worth of exhaustive data collection and market research, the PV ModuleTech Bankability Ratings were unveiled on stage, ranking the world's top module makers based on manufacturing and financial health. An animated hum, punctured by whispers here and there, spread swiftly throughout the conference room as the rankings flashed on screen, revealing those in and those out.

Days later, as the return journey beckoned, a common thread started to emerge when thinking back to Malaysia's technology talk, Shanghai's industrious crowds and factories and Taipei's packed conference halls and night markets: the sheer speed at which Asian solar is – much like the continent that hosts it – embracing disruption, transforming itself even as it transforms global solar in the process. The impression lingering on this correspondent's mind after stepping off the plane in London was that whatever solar's next chapter has in store, it will likely be written by an Asian hand. ■

Credit: Solar Media

PV ModuleTech 2019 assembled downstream and upstream PV players to discuss their shared challenge: the dizzying pace of module innovation

PV ModuleTech Bankability Rankings: methodology, validation and supplier ratings for Q4'19

Module bankability | Understanding the bankability of module suppliers is a critical aspect of solar project development. Finlay Colville, head of research for PV Tech & Solar Media, presents a model that allows scoring, rating and benchmarking of PV module suppliers by bankability for commercial, industrial and utility segment deployment. Quarterly rankings enable project developers and site investors to shortlist module suppliers when seeking to minimise module supplier risk and maximise site returns over the lifetime of owned assets

Bankability is one of the most critical requirements for PV module suppliers during selection for commercial, industrial and utility (CIU) projects. Until now, the industry has lacked an accepted mechanism to rate suppliers by bankability.

During 2019, the research team at *PV Tech* developed a model using manufacturing and financial data collected over 10 years. The goal was to establish a means of benchmarking any PV module supplier, at any time (quarter), within a 0-10 bankability scoring range, allocated to ranking grades from AAA (highest) to C (lowest).

During August to October 2019, the methodology was explained with a series of articles on *PV-Tech.org* [1], with findings validated against historical and current trends. The first output from the *PV ModuleTech Bankability Rankings* was published during November 2019 [2].

This article summarises the key features of the model, how validation was undertaken, and which companies were revealed as the most bankable suppliers at the end of 2019.

Methodology overview

Investment-risk (or bankability) scores for module suppliers are obtained by combining manufacturing and financial health scores using statistical analysis (nonlinear/power regression), with data dominated by quantitative inputs (six years back, two years forward), and qualitative data kept to a minimum. Validation is done by comparing to sample groupings and how different module suppliers are/were perceived from a bankability standpoint.

The relationship between supplier bankability (B), manufacturing (M) and financial (F) health scores follows a simple nonlinear relationship:

$$B_i = k.\,M_i^m F_i^n \qquad (1)$$

where k is a scaling factor mapping bankability scores to a 0-10 band, m and n are power coefficients, and i is a variable (supplier and time-period specific).

The manufacturing score, M, for suppliers, at any time, is determined by gathering data for each company (annually back to 2013, by quarter to Q1'15), and analysing the dependency of this data on overall bankability. The final manufacturing score is a combination of module supply (shipment), capacity and technology-driven ratios:

$$M_i = a.\,S_i^p + b.\,C_i^q + c.\,T_i^r \qquad (2)$$

where a, b, and c are factor-dependent weightings, scaled to generate manufacturing scores for each company by quarter from 0 to 10; S, C and T are shipment, capacity and technology ratios; p, q and r represent power factors.

Manufacturing supply (*S*)

The manufacturing supply factor (S) captures market share by branded module shipments (assembled at company-owned facilities and outsourced/third-party entities).

The analysis identifies each supplier's shipments (*Ship*) by quarter, allocated to six ($j = 1\ldots6$) end-market regions (*Reg*), confined to non-residential (CIU) contributions (*Ship'*), and consolidated using trailing 24 months (*t24m*) of data.

For each company (i), quarterly CIU shipments by region are summed over eight previous quarters (*t24m* at quarter ends), and converted into regional market shares by dividing this by the *t24m* sum of total shipments (CUI specific) in each region,

$$Ship'_i(Reg_j)_{t24m} \Big/ Ship'_{Total}(Reg_j)_{t24m} \qquad (3)$$

However, market share in any region is only relevant if strong demand is expected going forward. To address this, two scaling factors are applied. The first considers total future CIU demand (*Dem*) in each of the regions, as a percentage of the overall total global CIU demand, two years out at the end of each quarter or forward-24-months (*f24m*).

The inputs here are among the few qualitative data entries within the analysis, based on forecasted demand (module supply) two years out from any given quarter-

$$Dem'_{Total}(Reg_j)_{f24m} \Big/ Dem'_{Total}(Global)_{f24m} \qquad (4)$$

The second introduces end-market risk; critical to understand because policies and demand-related factors create uncertainty. These have a direct impact on the relevance of legacy market-share coverage (shipment volumes). A demand-specific risk factor (*Risk*) is introduced by quarter/region, based on the *f24m* period at any given time:

$$\left\{1 - Risk'_{Total}(Reg_j)_{f24m}\right\} \qquad (5)$$

Supply scores are thereby assigned to all suppliers at each quarter-end; for CIU deployment into each of the six regions; based on historic market shares (ratioed against *t24m* global CIU demand) and scaled against future (*f24m*) regional CIU demand and associated demand-risk.

The final score for suppliers (at each quarter-end) is the sum of the scores in each region:

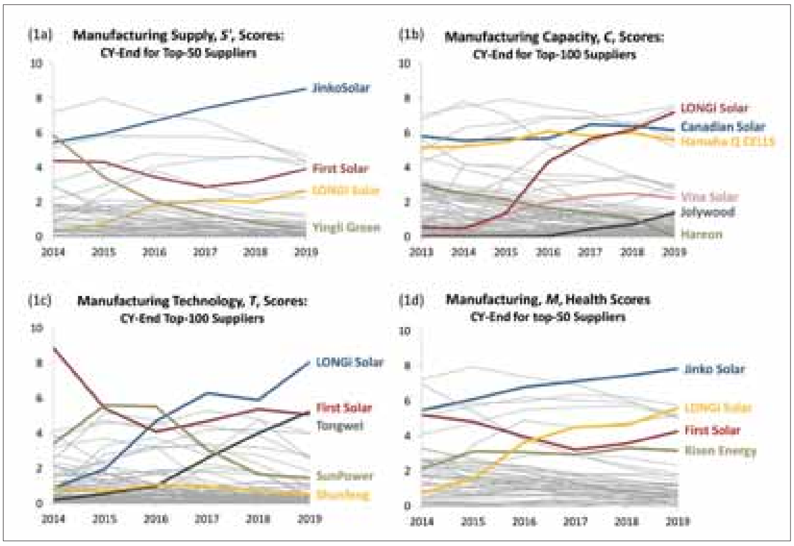


Figure 1. Output from the analysis of PV suppliers across manufacturing health metrics, with examples highlighted for validation purposes

$$S'_i = k_s \sum_{j=1...6}\left[\left\{\frac{Ship'_i(Reg_j)_{t24m}}{Ship'_{Total}(Reg_j)_{t24m}}\right\}.\left\{\frac{Dem'_{Total}(Reg_j)_{f24m}}{Dem'_{Total}(Global)_{f24m}}\right\}.\left\{1 - Risk'_{Total}(Reg_j)_{f24m}\right\}\right] \quad (6)$$

(6)

The scaling factor *k* assigns scores in 0-10 bands, set quarterly by looking at the distribution of scores and standard deviations. Figure 1a displays sample data output for supply scoring.

Manufacturing capacity

The manufacturing capacity factor (*C*) ranks suppliers by evaluating in-house cell and module quarterly effective capacities across different global manufacturing zones, and factoring in the access these zones have at any given time to global end-markets.

The analysis starts by segmenting each company's effective quarterly cell and module capacities (*Cap*) across eight manufacturing zones ($p = 1...8$): China, Taiwan, India, Japan, Southeast Asia, the US, Europe and Rest-of-the-World.

The next stage determines how much effective in-house cell capacity is available to each module supplier in the zones. This allows differentiation between modules produced by any company (in any zone) using in-house cells (*IHC*) or third-party cells (*TPC*). The resulting module capacity by company (*i*) is:

$$c_1.Cap_i(IHC_P) + c_2.Cap_i(TPC_P) \quad (7)$$

The *c* coefficients are weighting factors depending on whether module capacity uses in-house cells made in the same zone, *Cap*(*IHC*), or by third-party cell producers, *Cap*(*TPC*). This promotes the strength of module suppliers that use in-house cells produced local to module assembly. The weighting factors, *c*, are qualitative, adjusted by quarter and by manufacturing zone, depending on how important in-house vertical integration is.

The next stage introduces the impact of trade (export) restrictions on modules produced within each zone and shipped to any of the six ($j = 1...6$) end-market regions (*Reg*) introduced earlier.

To restate module capacity by company/quarter within the zones, each capacity value (obtained through the summed term above) is multiplied by an end-market 'access-related' factor that is both manufacturing-region and end-market specific. The module sum factor for each supplier is multiplied by a quarterly-variable term based on combining the total quarterly CIU demand (*Dem'*) (for each end-market) with a qualitative access percentage term (*Access*) that defines the availability of end-market *j* for module production in zone *p* at any given quarter.

The pro-rated regional contributions for each zone are scaled by dividing by the total global CIU market demand each quarter. The overall scaling factor is:

$$\frac{\sum_{j=1...6}\{Dem'_{Total}(Reg_j).Access_{p,j}\}}{Dem'_{Total}(Global)} \quad (8)$$

This analysis not only adjusts module capacity by manufacturing zone, but also scales the size of the served end-market by the importance of each region, looking at the ratio of the demand (CIU) from that region and the total CIU demand each quarter.

The final capacity score (*C*) for each supplier is the sum of the scores derived from all manufacturing zones by quarter:

$$C_i = k_c \sum_{p=1...8}\left[\left(c_1.Cap_i(IHC_P) + c_2.Cap_i(TPC_P)\right).\left\{\frac{\sum_{j=1...6}\{Dem'_{Total}(Reg_j).Access_{p,j}\}}{Dem'_{Total}(Global)}\right\}\right] \quad (9)$$

where *k* is a variable quarterly scaling factor, to map capacity scores to 0-10, again based on distribution and standard deviation checks by quarter.

The capacity analysis is confined to quarter-only data, not trailing or forward-looking, because capacity strength is an instantaneous variable (has a specific value at any time), dependent on trade-access conditions. Figure 1b displays sample data output for capacity scoring.

Manufacturing technology

The manufacturing technology factor (*T*) ranks suppliers by investments into capital expenditure (capex) and research and development (R&D). For capex, only cell and module stages are extracted by quarter (removing polysilicon, ingot or wafer capex if consolidated).

The analysis starts by isolating total PV manufacturing capex by quarter for each supplier, removing allocations to polysilicon/ingot/wafer, to leave cell/module contributions; *Capex*(*CM*). Weightings are not applied to cell and module because each is generally equally advantageous.

Capex is included across facilities, maintenance, upgrades and new lines. For thin-film, it is necessary to normalise (derate) capex allocations (adjusted annually) due to higher spending compared to c-Si.

For each module supplier (*i*), the respective quarterly cell/module capex values are converted into *t24m* sums because capex by quarter tends to be lumpy.

Capex scores (0-10) for each supplier (by quarter) are found by analysing the data distribution, and normalising each quarter (*u*) for benchmarking. Since capex follows cyclic trending, this promotes investment during downturns.

R&D spending, *R&D*(*PV*), follows similar methodology to capex, but excludes only polysilicon. Quarterly spending is assigned to each supplier, with *t24m* values at quarter-ends, and scores are converted to 0-10 based on normalisation each quarter (*v*). Again, R&D investment during downturns is emphasised.

To establish technology-based quarterly scores (*T*) by module supplier (*i*) for any quarter, the two scores (capex, R&D) are combined by applying weightings (prioritised to capex), denoted by the *t* coefficients below. The final step is to normalise each quarter to 0-10 through quarterly coefficients *k*, yielding:

$$T_i = k_t.\{t_1.u.Capex_i(CM)_{t24m} + t_2.v.R\&D_i(PV)_{t24m}\}$$

(10)

Figure 1c displays sample data output for technology scoring.

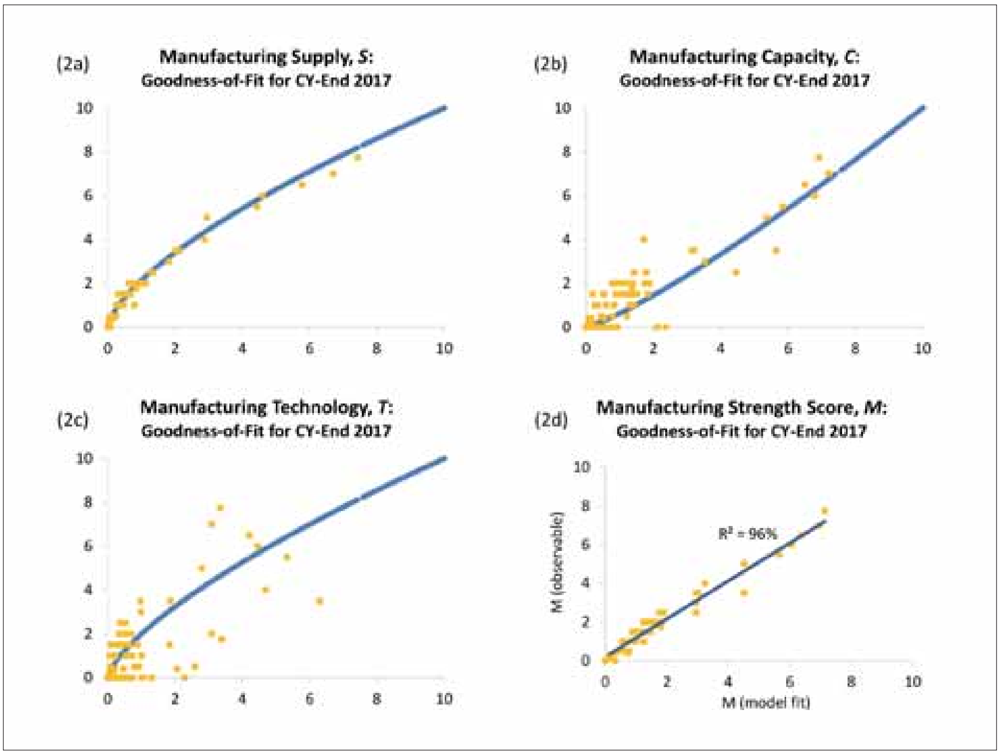


Figure 2. Validation of the manufacturing analysis, including the dependency of supply, capacity and technology variables, and the overall fit to module suppliers' historic (observable) bankability status

Manufacturing strength

Manufacturing strength (*M*) considers the dependence of the three manufacturing variables as given by Equation (2). To understand the dependence of *S*, *C* and *T*, it is useful to compare with final model accuracy (goodness-of-fit); see Figures 2a to 2c. For each graph, the values of *S*, *C* and *T* are plotted (*x*-axis) against the original qualitative entries for each company's *M* scores (*y*-axis), with the sold line-fit based on the final terms $a.S^p$, $b.C^q$, and $c.T^r$, scaled to 0-10. The closer the scatter points to the line-fit, the stronger the dependence.

The profiles of the curves, in each of the *S*, *C*, and *T* plots, drives power factor determination for the variables. Coefficients are determined by combining the power dependency of each variable with the corresponding data fit accuracy and 0-10 scaling. The coefficients and power factors yield the overall weightings for *S*, *C*, and *T*.

Figure 2d provides a final check on the analysis (validation). The fit between the original qualitative *M* values (observable, *y*-axis) should be as close to a 1:1 linear fit, when calculating *M* using the modelled equation (all coefficients and factors determined), plotted on the *x*-axis. Figure 1d displays sample data output for manufacturing scoring.

Financial strength (F)

When benchmarking financial health of suppliers, a technique routinely applied is a model developed by Altman [3] as a measure of financial distress relative to potential bankruptcy. Despite a lack of checks on this scoring system relative to historical performance of PV companies, it remains a valid means of assessing 'financial strength' (least likely to go bankrupt). It is easy to generate Altman Z Scores for suppliers (or corporate holding entities): the challenge is how to interpret and understand them in context.

The approach applied here retains the integrity of the Altman model, but adapts the scores for correlation to PV. This involves two steps, starting from Altman Z Scores and ending up with new financial health scores (*F*) that rank companies 0-10 across new zones (score bands), validated with data observed in the sector.

The first stage involves gathering Altman Z Scores for suppliers or parent companies (warranty 'guarantors'). This uses quarterly-reported information, as opposed to annual information only. (The inclusion of privately held entities is discussed later.)

This is where traditional approaches have stopped, categorising Z Scores of PV companies within legacy Altman zones. However, typically more than half of top-20 suppliers (at any given time in the past decade) have scored at levels suggesting imminent bankruptcy.

Therefore, new Altman Z Score limits are established, representing 10-year upper/lower values of module suppliers, shown in the centre image of Figure 3 by the terms Best-in-Class (*PV-BiC*) for the upper, and Technically Bankrupt (*PV-TB*) for the lower. *PV-TB* can be viewed as a point of 'no-return' in PV, often referred to as 'zombie' modus-operandi.

Next, it is necessary to adjust Altman bands (safety, grey, distress) to new ones. The model retains three-level traffic-light coding (green, amber, red), renamed Comfort Zone (green), Zone-of-Uncertainty (amber), and Distressed Zone (red). Suppliers in the Zone-of-Uncertainty can recover operations (move to Comfort Zone) or descend rapidly (becoming 'unbankable').

The next step involves assigning PV financial scores (*F*) in a 0-10 band, where

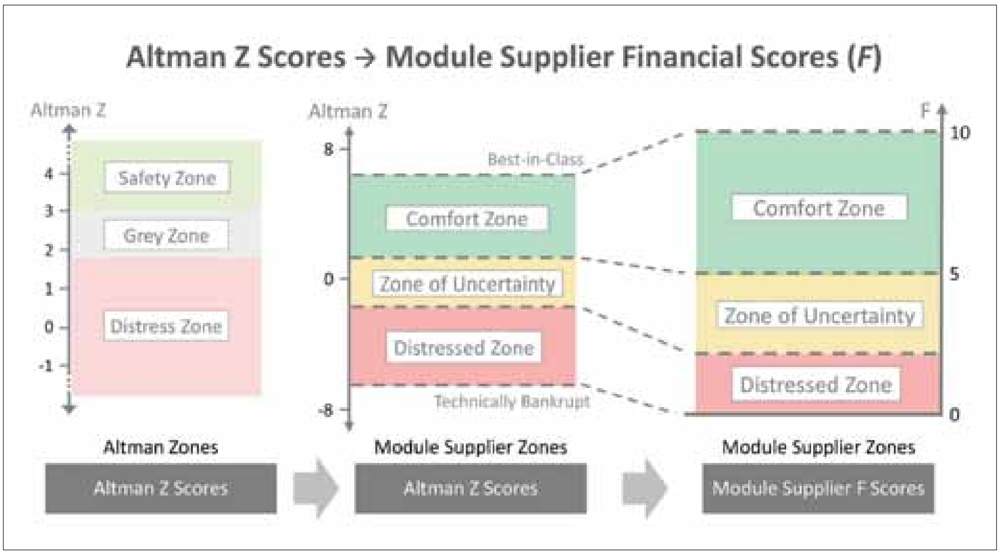


Figure 3. Schematic illustration of restating financial operating zones for PV module suppliers, with a new mapping function to assign financial health scores within a 0-10 range

scores above 5 (or 50%) fall into the Comfort Zone. Mapping Altman Z Scores (labelled

$$F_i = 0, if\ A_i \leq A_{PV-TB} \quad (11a)$$

$$F_i = \beta_0 + \beta_1 A_i + \beta_2 A_i^2 + \cdots + \beta_n A_i^n, if\ A_{PV-TB} < A_i < A_{PV-BiC} \quad (11b)$$

$$F_i = 10, if\ A_i \geq A_{PV-BiC} \quad (11c)$$

The key term, shown by Equation (11b), involves mapping using a polynomial of order *n* (coefficients given by β terms). The best-fit solution is determined by approximating upper and lower values of *F* (10 and 0) to successive local minima/maxima, mapping the boundary data sets (distressed/uncertainty and uncertainty/comfort), and reducing to a set of simultaneous equations.

A final correction deals with one-off accounting issues and smooths out seasonal lumpiness, by using trailing twelve months (*ttm*) averages.

Bankability strength (B)

The bankability strength (*B*) relationship is relatively intuitive, directly scaling the manufacturing (*M*) and financial (*F*) values; see Equation (1). To be bankable, suppliers must have manufacturing strength and demonstrated financial health status at the same time. The challenge is to identify the scaling constant (*k*) and power factors (*m* and *n*); and validate with sector activity.

This is done by comparing the output to actual supplier standings (observables), based on various suppliers in the past, in addition to the current landscape. The solution starts by considering anchor points of the bankability, *B*, scoring band; from lowest bankability score (0) to highest (10). The lower bound is self-explanatory:

$$B_{min} = 0, if\ M = 0\ or\ F = 0 \quad (12)$$

The conditions governing the upper band are more complicated. In theory, one would expect maximum bankability score

$$B_{max} = 10\ if\ \begin{cases} M = 10 \\ F = 10 \end{cases} \quad (13)$$

While theoretically possible, it is practically unattainable. If the coefficients are set using this boundary condition, then few (if any) suppliers achieve bankability scores above 50%.

This anomaly is resolved by removing one-off outliers (extreme values) in the datasets for *M* and *F* scores, and introducing percentiles with the maximum value of *B* now given by:

$$B_{max} = 10\ if\ \begin{cases} M = M_v\left(P_m, (N_m)_{t3y}\right) \\ F = F_v\left(P_f, (N_f)_{t3y}\right) \end{cases} \quad (14)$$

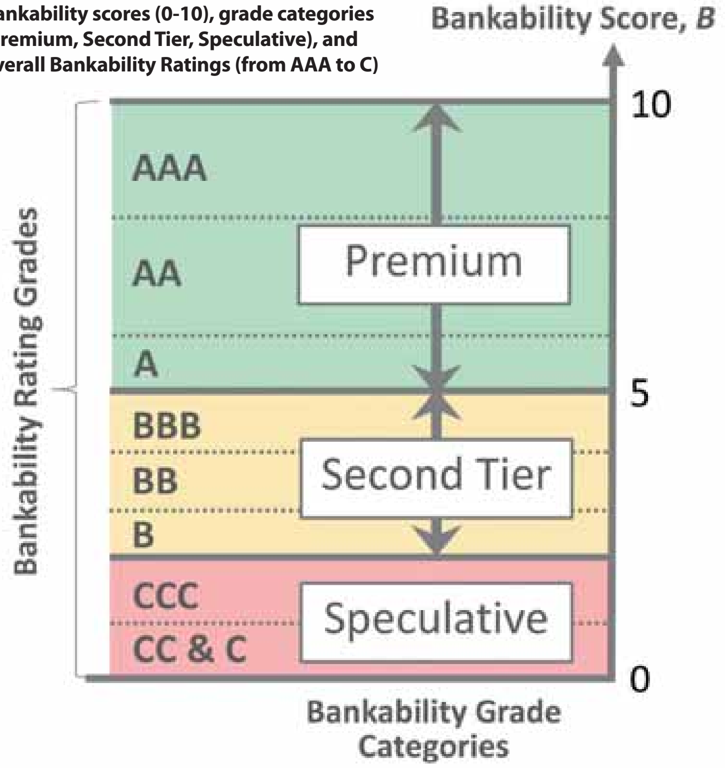
Here, M_v and F_v are percentile values of *M* and *F* across a total of N_m and N_f data entries over a trailing three-year period (*t3y*), and P_m and P_f are input percentiles for *M* and *F*.

The final step is to set the ratio of the power coefficients, *n* and *m*. The solution is achieved by recognising that financial health is more important than manufacturing health. The solution to *k* is:

$$k = {B_{max}}/{(F_v^n . M_v^m)} \quad (15)$$

Bankability scores (0 lowest, 10 highest) are assigned to three grade categories: Premium, Second-Tier, and Speculative. Suppliers with scores in the range 5-10 are placed in the highest (Premium); in contrast, lowest performers (scoring 0 to 2) are in the Speculative grade. Each grade has three rankings/ratings (e.g. Premium includes AAA, AA, and A), shown in Figure 4.

Figure 4. Definition of module supplier bankability scores (0-10), grade categories (Premium, Second Tier, Speculative), and overall Bankability Ratings (from AAA to C)



Privately held companies

There is no widely accepted means of benchmarking public and privately held module suppliers. To address this, the route chosen [4] was to derive a practical/approximate variant, guided by two themes: equate with the public-listed Altman ratio-discriminant model; choose inputs that can be realistically obtained from privately held suppliers (or parent entities).

There is an Altman equivalent for privately held companies [5]. It retains the concept of summing terms based on liquidity, leverage, profitability, solvency and activity, but replaces working capital and market capitalisation entries with alternate numbers/terms. It requires eight accounting terms to be known (compared to the listed version based on seven). It creates different scoring values/zones, making benchmarking challenging.

To address this, a modification of the public-listed Altman equation was developed, reducing the terms/ratios to a minimum, while keeping error bounds on final financial scores within acceptable bounds. This allowed decoupling the market-cap issue, and not seeking an equivalent value for private companies (such as book value of equity).

This was done by examining Altman Z scores derived for listed PV module suppliers (or parent entities), and identifying the significance of the constituent terms, considering actual data that could be expected from private companies in practice.

In looking at module suppliers (and parent entities) that are publicly listed, there is a range of business models. To establish a shortcut to reaching financial strength scores, it was necessary to form test groups where chosen companies operate with similar characteristics.

With the goal at +/-10% equivalence to scoring generated from the initial five-ratio Altman Z approach, the number of ratios could be reduced from five to three for each test group. The coefficients for the

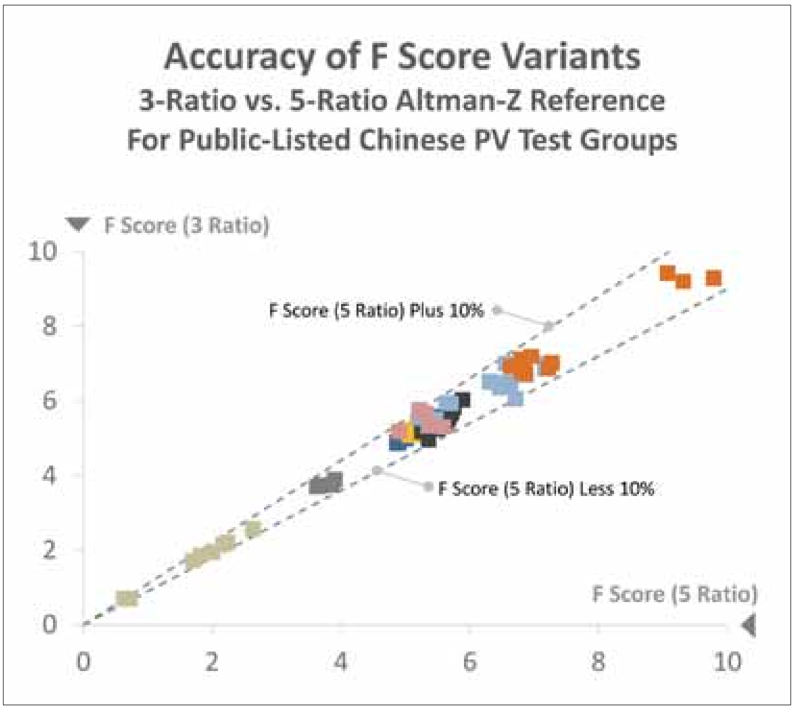


Figure 5. Accuracy of the new three-ratio reduced-Altman method, compared to the full five-ratio version applied to public-listed suppliers. Privately-held entities are scored using the three-ratio model valid for the peer-group each is assigned to

three chosen ratios (noting that a scaling constant is essential now) were determined using a least-squares linear regression analysis, where the 'residual' is the difference between the original five-ratio Altman and the new reduced three-ratio approach.

To test the validity of the new approach, the level of accuracy for the reduced-fit model can be assessed when applied to a known dataset (public-listed PV module suppliers/parent-companies); see Figure 5. The original (full-analysis) Altman Z scores going back 3-4 years for each company, converted to the 0-10 (*F*) scoring band as explained before, are on the *x*-axis; the equivalent 0-10 financial scores, using the new shortened variant, on the *y*-axis. The match of the shortened variant with the original Z score value is the test of the approach validity.

This is visualised in Figure 5, where a 1:1 line-fit would represent 100% accuracy. Shown are two dashed straight lines above and below 1:1 fitting, with upper/lower bounds at +/-10% accuracy.

Supplier rankings for Q4'19

The first release (Q4'19) of the *PV ModuleTech Bankability Rankings* report revealed exclusive status for four suppliers (JinkoSolar, LONGi Solar, Canadian Solar and First Solar), as the only companies with AA-Rating. No companies scored in the AAA-Rated band.

The Q4'19 report release from *PV Tech* contains in-depth company-specific analysis across key manufacturing and financial metrics forecasted to the end of 2020, for A and B ranked suppliers. The pyramid chart in Figure 6 displays the output hierarchy showing all A and B grade listings.

To be AA-Rated (or indeed AAA), companies need 10GW-plus CIU annual shipments coupled with moderate-to-good finances, or 5-10GW shipments (CIU) with strong finances. This explains why only a few companies are AA-Rated today, with the absence of AAA ratings also a consequence of low margins inherent to module sales.

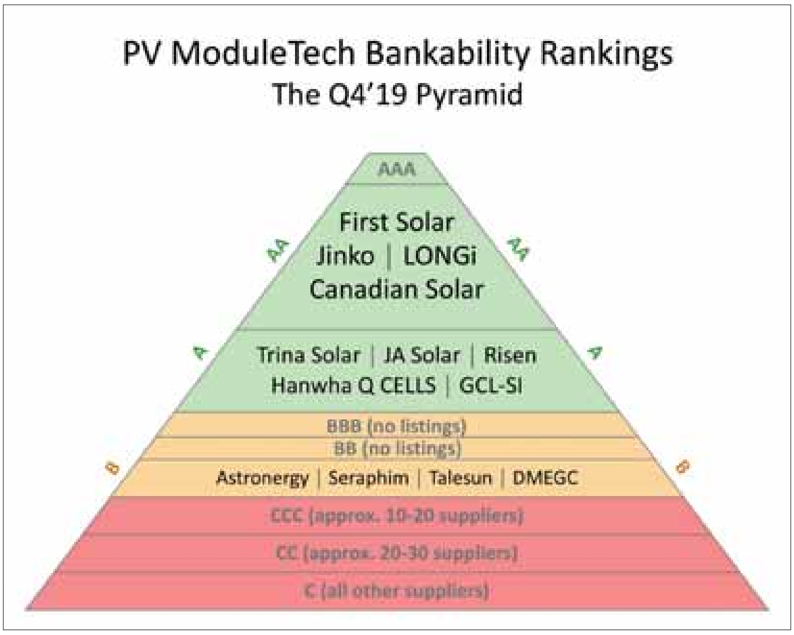


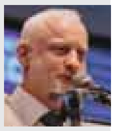
Figure 6. The PV ModuleTech Bankability Rankings pyramid for Q4'19, showing four suppliers having industry-leading AA-Rating status

Final discussion

The strength of the model developed to rank and benchmark module suppliers by bankability for CIU selection will be further validated by reviewing changes observed across the various rating bands over time. The first output from the Q4'19 dataset appears to suggest a very good match to the companies winning large-scale global supply business in 2019.

Since the model is comprised of a wealth of in-house and external factors important to manufacturing and financial health, the ability to forecast company-specific bankability one to two years out could become a highly sought after extension, in particular for supplier selection in large-scale projects that have multi-phase delivery schedules. During 2020, the model will be extended to allow for this option. ■

Author



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Balance-of-system components and new PV ecosystems

Testing and certification | Ensuring the safety, performance and durability of non-module components in a PV system is an ongoing challenge for the solar industry. Robert Puto of TÜV SÜD looks at the latest testing and certification programmes in place to help bring greater certainty to balance-of-system procurement

For those who like me believe in a carbon-free future, expecting a strong uptake of renewables is a safe assumption. We are going to see more residential, more commercial, more decentralised solar PV in years to come.

We have all been fascinated by the learning curve of the global PV industry over the last 10 years. The most remarkable result of that curve, as well as the most visible to most stakeholders, has been the relentless decline of PV module costs. With a lot of attention focused on their quality and price, we have gained solid knowledge to make informed decisions when it comes to selecting a suitable technology and a reliable vendor for our PV systems.

We can't say the same about balance-of-system components, which have not received the same attention, not until recently and for an obvious reason. For the purposes of this article, we define balance-of-system (BOS) as all components other than/beyond the PV module. Examples include wiring, inverters, mounting structures, combiner boxes, protective devices, switches, energy storage, etc.

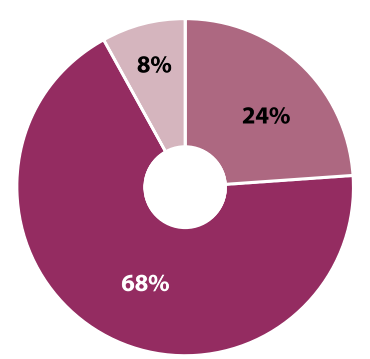


Figure 1. Contribution of the module, BOS and O&M costs to the LCOE of a typical solar system [1]

As prices hit new lows, modules have become a global commodity. This is not the case for BOS components. Their learning curve and cost decline have been much slower and over time their share of the CAPEX and overall LCOE of a PV installation has become dominant (see Figure 1).

It is also worth noting that the BOS landscape is more heterogenous than that of modules due to regional energy, environment and construction regulations.

Currently, BOS costs can make a difference in terms of capex. But a lower capex is not a guarantee for a shorter payback time and better ROI. Energy generation is. This explains the growing importance solar asset owners, EPCs and operators attach to the reliability of modules and BOS components.

Since day one, we in TÜV SÜD have developed reliability programmes alongside conventional IEC/EN/UL standards and certification schemes.

The approach is based on two types of criticalities: those detected, monitored and collected in the lab during testing, combined with those encountered during on-site tests and inspections of PV installations:

1) Reliability patterns during standard testing.
2) Reliability patterns occurring out in the field.

With more than 30GW+ of PV installations inspected worldwide, 1,000+ certificates issued for PV modules and 500+ for BOS components, we know where to focus on when it comes to reliability.

Failures continue to occur in PV installations and many of these are related to BOS components. Figure 3 shows some examples from the field of the consequences of failed components.

Let's have a closer look at services for the main BOS components.

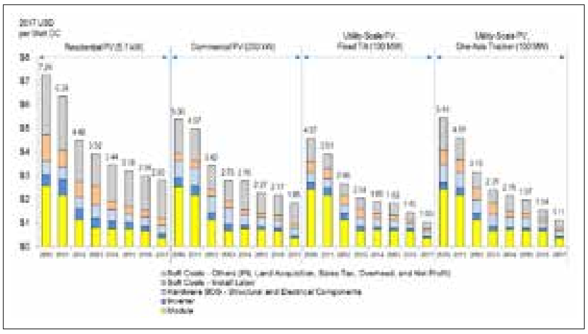


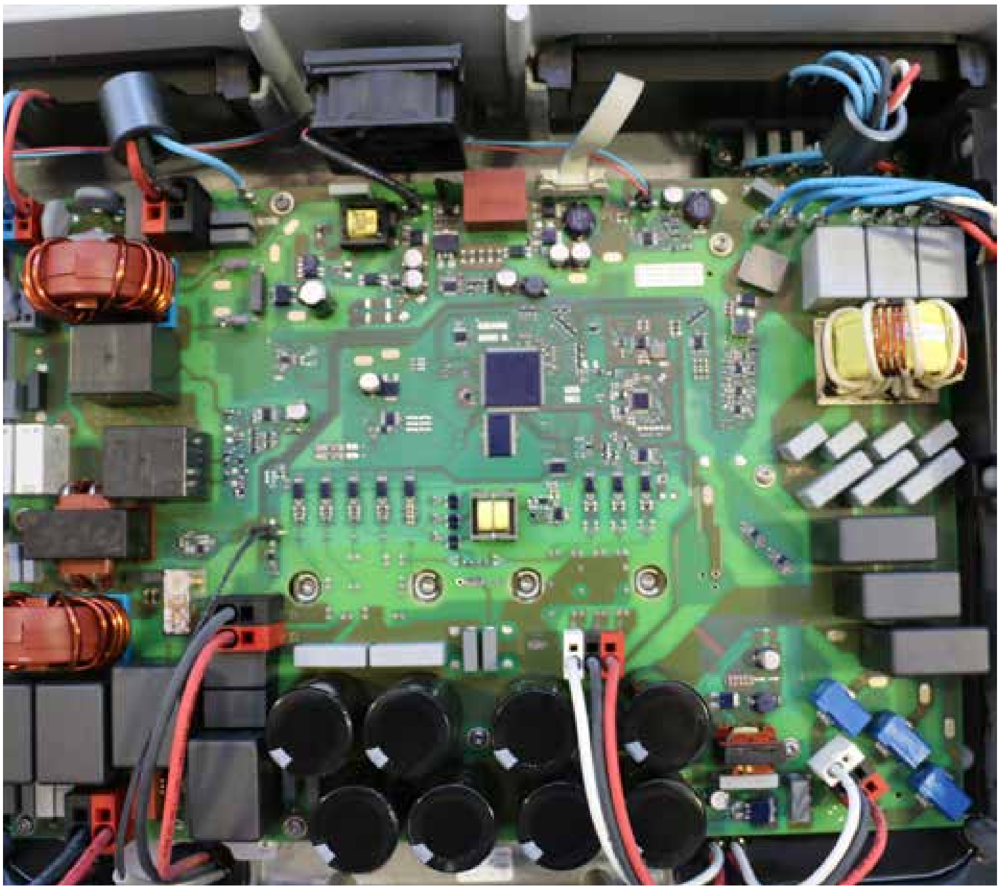
Figure 2. NREL PV system cost benchmark summary, 2010–2017 [2]

Figure 3. Examples from the field of BOS failures

IGBT inverter explosion/fire hazard caused by poor inverter quality and technical design.

Combiner box fire hazard caused by poor design and installation

Failure caused by poor mounting structure design



Credit: PVEL

Figure 4. Advances in inverter technology mean greater challenges from a testing point of view

Inverters

Inverters lie at the heart of all PV systems and as such are crucial to the reliability of the whole system.

Inverter technology has seen continuous advancement aiming to optimise system performance. An example is the adoption of 1,500V inverters as the result of PV module technology development towards 1,500V system voltage.

Higher system voltages require higher insulation strength for materials and components to withstand continuous normal system voltage and temporary abnormal voltages (eg. lightning surges). Consequently, increased clearance and creepage distances are required. This might imply either replacing old components with new ones or designing special solutions around existing components which can meet higher requirements.

As a matter of fact, achieving safety certification for 1,500V inverters to IEC 62109-1, -2 has resulted in a more challenging task than for 1,000V inverters. TÜV SÜD marks and certificates attest compliance of inverters with safety standards IEC 62109-1 and IEC 62109-2.

On the other hand, pressure to reduce costs has produced "collateral effects" in some markets. Chinese manufacturers, for example, have (understandably) decided to develop domestic alternatives to imported materials and components. Proving that new solutions offer the same level of safety and reliability is critical for asset owners. We at TÜV SÜD are addressing the matter through accelerated testing programmes based on IEC 62506 (Methods for product accelerated testing), combined with IEC 61709 (reliability of electrical components, failure rates and stress models).

TÜV SÜD reliability schemes are a very insightful tool for system designers and asset owners to evaluate and select the most suitable products. They enable informed decision making by reviewing and validating lifetime claims, warranty terms and maintenance contracts.

Cables

These are divided in two categories: PV and energy storage cables.

EN 50618:2014 and IEC 62930 are the optimal solutions for general purpose PV cables, in that by using them one can effectively evaluate UV resistance, electrical and mechanical properties, as well as the expected thermal life span.

Another interesting development is the increasing demand by EPCs for lightweight cables for use in specific applications. A TÜV SÜD programme will be soon released providing an evaluation method for aluminium conductor cables, covering both long- and short-term life spans.

Cables used in floating PV need to be evaluated against specific requirements such as resistance to salt mist, water tightness, resistance to low temperatures, etc.

A specific TÜV SÜD programme will be available in early 2020 also for these cables.

As for cables used in energy storage applications, in absence of specific IEC standards, TÜV SÜD China has developed a joint testing and certification programme (PPP 58049A: 2019) with Quality Certification Center (CQC). The first joint certificate was issued in July 2019.

Figure 5. Cabling for storage is not yet governed by any specific IEC standards

Credit: Powin Energy

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Mounting structures

Despite their small share in overall project costs, mounting systems have a significant influence on the long service life of PV modules. Only with a stable mounting structure over time can we expect optimal PV module power output. Environmental loads such as wind and snow, in combination with other specific climatic conditions (desert like, damp heat) need to be taken seriously.

PPP 59029 is a specific programme developed by TÜV SÜD in 2013, which provides a method to evaluate the environmental reliability to damp heat, thermal cycles and salt mist. The programme also uses finite element methodology (FEM) to simulate wind and snow loads per local regulations. After FEM simulation, an on-site load verification will be carried out.

Floating structures

As peaceful and relaxing as they look to the eye, floating solar installations hide tricky problems under the water. In 2019 the cumulative installed capacity of floating solar will exceed 1.2GW, with the prospect of doubling in just two years [3]. Due to low cost and mature industrial basis, polymeric floating body solutions are considered a very promising reality. However, currently there is no standard regulating polymeric floating bodies with a risk assessment behind it. In 2018, TÜV SÜD developed a specific programme, PPP 59073A – the world's first polymeric floating body certification scheme. It focuses on evaluating material properties (mechanical, burning characteristics, resistance to ageing), as well as product properties (buoyancy evaluation, tensile and shear strength of connection lug, fatigue test at design parameters and anti-wind capability).

Sun trackers

The prospect of adding an extra 10-20% energy yield on top is a tempting prospect, hence the increasing in use in large-scale PV plants. Being mainly a performance related element, TÜV SÜD developed the first performance evaluation method for solar trackers and issued the first IEC 62817 certificate in 2017. This is a design qualification standard defining methods to measure, calculate and evaluate parameters declared in specification sheets. Safety is not specifically covered by the standard, therefore a specific safety programme by TÜV SÜD is also available.

Protection devices

Several fire accidents in PV power plants have once again raised the alarm: root cause = DC arc fault. The US industry has been very responsive in tackling the issue by releasing UL 1699B: 2018, requiring all PV inverters sold in the US market to have a DC arc detection and interruption function.

IEC is currently working on a new standard (IEC 63027) to catch up on the matter.

TÜV SÜD keeps following the latest updates on the standard development, and this will be the future trend in testing and certification.

Figure 6. Floating solar installations involve a number of tricky engineering problems, necessitating a new set of standards


Credit: Smart Energy Council

Figure 7. Testing of smaller scale renewable energy storage systems covers critical safety and performance aspects

Energy storage systems

Given the intermittent nature of solar and wind energy generation, energy storage systems (ESS) have become the latest, extremely valuable entry of BOS components. They add value on multiple levels. By storing excess electricity and using it during times of peak demand they act as a buffer contributing to a more stable power grid. They are also the solution to the problem of power reliability in microgrid systems.

However, ESS technology maturity is yet to be achieved. Recent accidents due to battery fires, explosions and system mismatch show serious vulnerabilities linked to faults in batteries, battery management systems (BMS) electronics, power converters, etc.

While the industry actively invests in new solutions, the development of relevant technical standards is still lagging behind. With our extensive experience in solar/wind applications, and a worldwide network of battery laboratories, we have developed comprehensive testing schemes addressing the critical safety and performance aspects of residential, commercial/industrial and utility-scale energy storage systems:

1) Renewable energy storage systems – small and medium-size applications (residential, commercial, industrial). Testing & certification programme PPP 59034A: 2014. Covers:

- Battery/inverter safety, functional safety, EMC, global grid code compliance, emergency/stand-alone output quality, etc.

2) Utility-scale applications with PV/Wind. Testing programme PPP 59044A: 2015. Covers:

- Battery/converter safety, functional safety, EMC, round-trip efficiency, life endurance, walk-in system protection and safety, fire protection, electrical

installation electrical codes, global grid compliance, etc.
- On-site installation inspection and Final Acceptance Tests.

Industrial cyber security

Last, but not least. "Industrial IoT" is not a buzzword anymore; "smart energy" is the reality of interconnected energy assets exchanging data and interacting with each other to increase flexibility to changing conditions, enhance efficiency and maximise energy output.

The benefits offered by the digital transformation can be fully exploited only if they are risk-free. New hazards for people, property and environment need to be identified, assessed and mitigated. Given the critical nature of energy assets involved, achieving so-called "grid resilience" implies guaranteeing both "physical safety" and "cyber security".

The "secure-by-design" concept underlying IEC 62443 is the approach TÜV SÜD has adopted and recommends to address cyber security of commercial and utility-scale systems. Given the new nature of cyber risks, we are offering tailored training packages for product suppliers, system designers and asset owners. By sharing knowledge on cyber risk assessment, threat modelling and vulnerability testing, we are ready to engage together in a journey that starts with raising awareness, continues with gap analysis, implementation measures, evaluation and validation, and finally evolves in certification.

In summary, BOS components do make a difference, in terms of both CAPEX and overall system performance. Investors, asset owners, system designers and operators must pay closer attention to the criteria used in selecting their suppliers, keeping in mind that the real value of BOS components is a compromise between price and reliability. Overlooking safety and performance aspects can produce direct financial impact.

Standard testing and certification are necessary, but not sufficient. Specific applications, installation conditions demand deeper insight into reliability.

An example is the need for differentiated requirements for lightweight cables in floating PV applications. Likewise, desert installations, or energy storage systems, pose different challenges to cables and supporting structures. Another example is the wider adoption of bifacial modules, which will bring about an increase in the use of sun trackers.

Credit: Greensmith Energy

Figure 8. Testing of utility-scale storage applications covers battery safety through to on-site inspections

Looking ahead, two scenarios will shape the future of the sector: further decentralisation and smart energy solutions.

As a result, energy storage systems will be very soon the new, very important BOS entry. They require a new kind of knowledge that combines batteries, power converters, DC-AC coupling and energy storage management. A more comprehensive risk assessment is needed for the whole system.

At the same time, ongoing digital transformation of the energy industry offers new, smart energy solutions. Interconnected "digital" assets will make new energy ecosystems more dynamic and flexible to changes in the environment. Physical safety and cyber security of these (digital) assets are indiscernible. ■

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Mirror of sand: Middle East reflects US bifacial boom

Credit: TÜV Rheinland

Bifacial | The low prices achieved in some of the recent Middle Eastern solar auctions have been made possible in a large part because of the inclusion of bifacial module technology. Tom Kenning examines how booming deployment in the US is helping drive bifacial's uptake in the Middle East, where the conditions are optimal for the technology

Vast deserts of bright sand and rock make the Middle East a pristine location for installing bifacial solar modules, which can take advantage of the sun's irradiation not just from above but also reflected from the ground. In many respects, it is a no-brainer to deploy the technology in this region. However, no PV plants using bifacial panels have been operating long enough to provide bankability metrics and the industry also has a problem with hoarding rather than sharing data, which could be tethering the financial community to an unnecessarily conservative outlook. Rest assured, some companies in the Middle East and North Africa (MENA) must have access to encouraging data as the arid region has started to see its first bifacial projects of more than 100MW capacity being built this year. Otherwise, it may only be prospects of significant yield gains by generating power from the backside of the panels that has pushed some investors to take the risk of being early adopters.

What is now clear, that was once a mystery two years ago, is that some of the lowest solar tariffs in the world, located in this region, were based fundamentally on bifacial technology. Famously, ACWA Power put in a record low bid in Saudi Arabia that left the industry scratching its head, only for it later to emerge, as revealed by our website publication *PV Tech*, that it pinned its hopes on bifacial technology well ahead of the global curve.

Testing of bifacial technologies by TÜV Rheinland in desert conditions has shown promising early results

If the US market continues hoovering up bifacial panels with its current appetite, then there will be positive knock-on effects for other suitable regions like the Middle East (see boxout). This may leave one wondering if traditional monofacial modules have any long-term future in the region. Bifacial technology's potential could all rest heavily on the first data coming out of bifacial plants that have been operating for five years, but the industry must wait another two to three years for this.

Traditionally China has been the pioneer in bifacial adoption because of its Top Runner programme that incentivises high-efficiency technology, but with the US' growing appetite, the worldwide

Middle East PV projects are proving to be an important early adopter of bifacial solar technology, notably Egypt's Benban solar park

market has woken up to bifacial and the Middle East is an emerging market that is seeing much of the growth, says Xiaojing Sun, senior research analyst, global solar at Wood Mackenzie. The research firm projects bifacial installs of 175MW in the Middle East in 2019, but this is going to see "very rapid growth" to annual deployment of 2.1GW in the region by 2024. Manufacturer outlooks give credence to this forecast, with Chinese Silicon Module Super League (SMSL) member JA Solar expecting glass-glass bifacial modules to become the mainstay of the Middle East market.

"Compared with regular modules, the double-glass module is more advantageous in wind and sand resistance, working life and so on," Dr Xinming Huang, senior vice president, JA Solar, told *PV Tech* as early as February this year.

Indeed, the Middle East region has bifacial projects small and large emerging, from the El-Mor Renewable Energies' 2MW system in Israel, to Oman's major 600MW bifacial project pipeline. There is a 320MW giant plant tabbed for the United Arab Emirates (UAE) and nearby in North Africa, Egypt's 1.8GW Benban Solar Park, close to Aswan, has seen Oslo-headquartered developer Scatec Solar start grid-connecting a 390MW (6 x 65MW) project, the largest using bifacial in the world.

Sand-suited

The three main drivers for adopting bifacial systems are technology, climatic conditions and economics, says Johanna Bonilla, project manager, performance and analytics PV modules & systems, at testing body TÜV Rheinland Energy, which has been testing the technology in various desert settings. In terms of technology, the glass-glass structure offers a high resistance to weathering impacts, in a region that suffers high winds and storms. For climatic advantages, the desert, apart from superb irradiation, has sand with albedos ranging from 19% to 35% depending on whether the sand is clear, dark or has cracks. As the arid region also has less vegetation and a lower likelihood of bushes growing up seasonally, one can also calculate albedo with minimal variability, which is good for modelling expected yield gains. Some investors globally are even starting to put artificial bright surfaces beneath their panels, although this can come unstuck as we shall see later.

Data so far shows bifacial modules on fixed mounting structures with one-year in the field have gains of 12% in coastal desert climates (Saudi Arabia) and 8% in arid desert climates such as in the US, whose conditions in some areas are similar to those of the Middle East, says Bonilla. The challenge is that the gain depends not only on climate and technology, but also on the installation. Therefore, shading, mismatch losses, pitch and use of trackers all have effects. TÜV Rheinland has yet to see major differences resulting from temperature at the module level. While this data shows bifacial plants do have gains and are operating well in the first year, Bonilla stresses that data over five years is needed to say confidently what will be the long-term performance of such modules.

It's important for installers planning a bifacial installation to realise that bifacial modules operate with higher currents (8.5% to 10% more than the front-rated ISC) than monofacial systems.

Backside blunders

While a major regional challenge is soiling, says Dr Radovan Kopecek, one of the founders of ISC Konstanz, the key bifacial-related mistakes include failing to realise that inverters will need to operate at a higher current, poor construction – such as having the modules too close to the ground – and poor use of artificial albedo enhancers.

It's known that at least one major company in Asia put white rocks directly underneath its bifacial panels but without any placed in-between the arrays, resulting in very little yield gain.

Another common mistake is to survey a site and assume strong albedo throughout the year in modelling, only to discover grass and green bushes emerging during certain seasons which impact the albedo, says Xiaojing Sun. Grass, next to water, is the least reflective surface. Without uniform reflection on the backside, one may also face the "nightmarish" scenario of physical damage to the module in the form of a hotspot.

Secret weapon

Instead of bifacial rolling steadily in to become the mainstay of record-breaking projects over time, it snuck in as far back as September 2017, when Masdar and EDF put in a bid around US$0.0179 per kWh for the 300MW Sakaka project in Saudi Arabia. Mouths dropped to the floor across the world, but a few months later *PV Tech* revealed that the two firms were banking on bifacial technology in order to reach low tariffs, the likes of which had never been seen.

Local firm ACWA Power won the bid despite quoting a far higher tariff, perhaps reflecting a Saudi-authority fear over the long-term performance of bifacial technology. However, this October, ACWA Power also signed a 200MW project in Saudi Arabia based on bifacial technology with a bid of US$0.02752/kWh.

"We have already seen by 2018 bids of around US$0.03/kWh in Egypt and even lower for big utility-scale projects," say Bonilla. "This year for the tender issued by the Dubai Electricity and Water Authority (DEWA) the bids discussed were around US$0.017per kWh."

Back in 2017, margins for monofacial projects were wafer thin, but having bifacial as a secret weapon allowed players to have an extra cushion in terms of yield projections, says Ben Attia, research analyst, solar, at WoodMac. Nonetheless, the technology is still being treated with a bit of caution, he adds – "with kid gloves".

Blind banking

As we've heard, data is a missing piece of the puzzle that is closely tied in with the bankability and financing of bifacial.

EDF evaluated bifacial technology at a very early stage, says Kopecek, and after spreading doubt about it, then made the first offer ever below two US cents per unit in Saudi Arabia with bifacial modules at the Sakaka plant, as mentioned earlier.

Meanwhile, Scatec Solar's 390MW Benban installation in Egypt was the first major bifacial project to be supported by banks, meaning that it had enough data to show to banks that the technology was bankable. Module supplier LONGi also gave a guarantee on the bifacial gain in the system.

"The biggest problem for the bifacial community is that this data is not shared between companies," says Kopecek. "I can understand it because they would like to install maybe other large systems in very similar scenarios and so they do not share with others."

Ultimately, laboratory measurements of reliability are too distilled to make a technology bankable. ISC Konstanz has itself carried out testing for a huge bifacial system of 200MW capacity and calculated a gain of more than 12%.

"Validation is needed to build trust and to consider a project or a technology bankable," says Bonilla. "The lack of data and the fact that this a new technology is actually making the financing conservative. It will take a while to build trust but it's moving in that direction."

The European Bank for Reconstruction and Development (EBRD) was the bank that backed Scatec Solar's Benban plant.

"It was a good opportunity for us to understand more the implications of installing bifacial panels in a big plant," says Ahmad El Mokadem, principal banker at EBRD. "How would you beat the fact that there is not much data? And the short answer is that you have to wait and see. This development is well proven, but it comes with some risks that may not be assessed at the very beginning, including for example the impact of overheating on degradation given that you are now employing both sides of the panel. We have even less than a year of operations so it's really early stages for us to assess."

El Mokadem stresses that EBRD likes to bank projects on the basis of very conservative bifacial gains in the base case analysis. From a lending perspective it is also important to have a strong sponsor and an EPC contractor who will be able to back a more conservative guarantee in terms of performance of the plant, he adds.

Investors are getting more comfortable with the technology after some initial reticence to understanding the actual gain, says Attia. This is due to the early adopters at Benban and the low tariffs across the region in Egypt, Jordan, Tunisia, the UAE, Oman and the pending Saudi Round 2.

"Most of them are predicated on favourable financing assumptions for lots of reasons in the Middle East, but also on pretty aggressive technology assumptions as well," says Attia. "And increasingly, we're starting to see that developers are not able to compete in some of those tenders, without assuming the adoption of bifacial technology."

Credit: Radovan Kopecek

Chile's 2.5MW La Hormiga project. Bifacial technology is well suited to conditions in the South American country

US bifacial boom to lift Middle East

Bifacial modules with trackers are fast becoming standard in the US, spurred on by the dropping of import taxes from Asia last summer, which has knock on effects for the rest of the world. Lobbies are pushing for the reintroduction of the taxes, according to ISC Konstanz's Radovan Kopecek, making the US a kind of "wild West" at the moment. Many large EPCs have told him, however, that even if the taxes were reintroduced next year then they would still choose bifacial now that they know more about the technology.

If 90% of US solar installations in 2020 use bifacial with trackers, then the technology will come more naturally to the Middle East as it will be made bankable and therefore more easily installed in other geographies.

"Then the US market will be bifacial markets almost 100% for large systems," says Kopecek. "This will be more or less reflected to the MENA states."

US demand will not be a problem for the Middle East either, since the US has implemented so many layers of tariffs, according to Xiaojing Sun of Wood Mackenzie, there is only a specific slice of global manufacturing capacity that can cost-effectively access the US. This is mainly in Southeast Asia, where they are spared of the anti-dumping and countervailing duties that Chinese and Taiwanese manufacturers will need to pay, and the 301 tariff specific to China. Southeast Asian manufacturers represent less than 8% of the total global capacity so the majority of bifacial capacity is still in China and this can easily supply the Middle East without impact from high demand in the US.

Bifacial beyond

Whatever happens in the Middle East, bifacial technology certainly has a grip on the world market, with Enel planning a 400MW+ system in Chile and a Chinese firm building a 500MW system in Hangzhou. The industry is now awaiting the first 1GW project and Kopecek reckons that a sub US$1 cent/kWh tariff with bifacial modules and trackers could come in three years.

Bifacial is here to stay, says Sun, who believes most detractors can only point at marketing exaggerations rather than truly challenging the technology. Moreover, the industry as a whole is now more mindful of exaggerated claims such as 20% electricity generation bonuses. More importantly, there are many data collection projects underway all around the world, collaborating behind laboratories and vendors to really test bifacial performance:

"Once we have that wealth of data, the market is going to become more rational. And if the data does show favourably about bifacial, which I believe they will, it will [attract] more mature institutions, investors and financial institutions to actually throw their weight behind bifacial products financing." ■

A busbar-less module technology for BIPV: Integration in an "Art Noveau" building cover in an historical area

BIPV is expected to become the fastest growing PV market segment in western countries, in Europe, USA and Middle East. Solar modules on roofs and facades will constitute a large part of this segment, with high potential of generation of renewable electricity. To meet the demand they have to be powerful and beautiful. S'Tile has developed an innovative solution for PV integration. The proprietary process interconnects cut cells from pad to pad, avoiding ribbons running along the cell. This provides a high peak power together with nice aesthetics. Modules appear royal blue when using poly or fully black when using monocrystalline silicon, similar to thin films with the difference that they present twice the power as they use silicon wafers.

The architectural project presented here took place in the old historical area of Montpellier city. It was replacing an old "Art Nouveau" marketplace with an approach mixing classical Baltard design and modern style. After one year of production, the installation has produced 77.5MWh, that represents five times the consumption of the marketplace itself. A record of production was obtained last May, 29th with 428kWh.

▲ 990 modules have been installed with an estimated Power of 65kWp ; they show a tetragonal shape with five different dimensions to fit the circular area of the roof

▲ The glass/glass modules are 50% transparent to allow visibility, according to the architect's specifications, of the grey metallic colour of the underneath roof cover

▶ Due to the absence of very unsightly copper ribbons on the front of cells, and the neutrality and homogeneity of the colorimetry, a new field of architectural solutions is possible on BIPV. These solutions allow for a development of PV in sectors where it was hitherto proscribed. In addition, these very high conversion efficiencies combined with valuable material savings, reduce the manufacturing costs in €/W of modules and the carbon footprint of the industry. S'Tile's glass/backsheet or glass/glass versions and are IEC/EN 61730 and IEC/EN 61215 compliant

In addition to power and aesthetics, this busbarless technology reduces significantly the amount of metals used for interconnecting cells in the module. This saves up to 75% of copper and tin (ribbons) and nearly 25% of silver on front of cells. By choosing monocrystalline silicon and using an advanced process such as PERC, modules can achieve conversion efficiencies of more than 20%. Full uniformly black modules can also be produced. In this case the stylistic panels are discreetly integrated on facades and covers of a house or of new or old buildings.

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Project briefing

MOVING THE NEEDLE FORWARD

Project name: York Solar Farm
Location: York, UK
Capacity: 34.7MW

When it was announced in early 2019 that UK developer and EPC Gridserve was laying claim to designing and constructing one of the most technologically advanced solar farms in the world in York, a northern city in the UK, there was a degree of trepidation in the sector.

But that is exactly what Gridserve has produced, unveiling a 34.7MW solar farm that boasts bifacial panels and single-axis trackers, a first for the UK solar market and what is thought to be the most northerly combination of the two technologies in the world.

Gridserve broke cover in February this year with York, and a sister project located in Hull, that have a combined generation capacity in excess of 60MW. One of those projects has been underpinned by a power purchase agreement with Warrington Borough Council, providing the council with its annual power demand.

Construction of the sites has been financed by international bank Investec and Leapfrog Finance, including a financing agreement that took in thousands of pages and incorporated detailed calculations based on the sites' prospective performance, and detailed analysis by DNV GL.

But the real detail lies not in the pages of a financing agreement, but in the planning – and execution – of a solar farm that, in truth, is years in the making.

Moving the needle

The site itself was known well to Gridserve chief Toddington Harper, having already secured planning consent for the land at his previous company Belectric, sold to German utility innogy after the UK's ROC-rush of 2012-2016. Some new, additional consents were needed, but the land, planning and, pivotally, grid connection potential remained largely the same.

The land itself is relatively low-grade – 3B – agricultural land, meaning its use for farming and crop cultivation is limited. There's a pig farm located nearby, but years of use of pesticides and other chemicals has impacted the land's potential for farming, making it an ideal plot for a utility-scale solar farm.

Credit: Gridserve

The true value of the site lay, however, in the aforementioned grid connection. Given the saturation of renewables in certain parts of the country, gaining a grid connection agreement can be notoriously difficult in the UK. At the York site, Gridserve was able to negotiate not just for an export agreement, but for an import connection agreement too, allowing the project to draw from the grid should it become economically beneficial for it to do so, posing significant benefits for revenue streams and project economics.

> "You can't move the needle by building the same type of solar projects that we used to"

And it's those revenue streams, driven by the combination of bifacial panels, trackers and battery storage, which have allowed for the project to come forward without the need of subsidies. Harper's previous developments at both Belectric and community energy-focused initiative Big60Million relied heavily on subsidies to bring projects forward, however Gridserve has had to think outside of the box and be progressive in its adaptation of business models to bring solar into the realms of economic feasibility.

"You can't move the needle by building the same type of solar projects that we used to," he says, adding; "We needed to work out how to make the business case work again, because without subsidies we'd lost a really valuable part of the income."

In replacing that revenue, Harper and Gridserve went back to the drawing board and all but redesigned a solar farm from the ground up, taking into account marginal gains provided by new technologies, greater efficiencies and new revenue streams available to solar farms. "How can we extract more value, to at the very least make up for what we lost in terms of income from the subsidy era? The solution is all about replacing artificial value in a subsidy with real, sustainable value elsewhere," he says.

"We've done a deep dive into each area, seeking the best possible technology, the optimum solution that currently exists on

Project specifics

Storage Capacity: 30.4MWh
Panels: Suntech bifacial
Trackers: NextTracker single-axis
Inverters: Sungrow
Batteries: Samsung

By Liam Stoker

the planet which is bankable, proven, but really still at the top end of the game, and then we've worked out how to combine those best-of-the-best pieces, individually, into a single project, so you get an overall concept of synergy i.e. the whole is greater than the individual parts. And that's what we're seeking. That's the objective."

With each of those three technologies playing a crucial role in the project's economic feasibility, their respective roles were carefully designed.

In pursuit of albedo

Many an eyebrow was raised at the inclusion of bifacial panels in the York project. There's a near industry-wide consensus that bifacial panels make perfect sense close to the equator and in certain applications, but on agricultural land in the north of England? The jury was out.

Harper, however, is adamant that bifacial panels in this project make "perfect sense", given the amount of natural diffused light there is in the UK. This stems from a need to utilise as much irradiation and eke as much generation from each and every panel on site given the lack of subsidy support.

"You need to harness as much energy at the lowest cost possible, which in our opinion makes bifacial panels a pretty obvious part of the solution," he says, noting that opting for bifacial panels did not add a material additional cost to the project's capex over more traditional monofacial panels.

Attaching a value to the performance boost recorded by bifacial panels is a complex calculation owing much to a number of moving parts, not least of all the albedo effect. A not insignificant amount of modelling was conducted by Gridserve as it sought to assess not just how bifacial panels could bolster project economics, but how operating conditions and the albedo effect could perhaps be manipulated.

No stone was left unturned – quite literally – in Gridserve's pursuit of performance as attention quickly turned to what was happening underneath the rows of panels. Spreading white chalk was considered, as were other surfaces and materials, but Harper has taken inspiration from previous projects once again for this and stumbled upon a solution that could set a precedent other developers and bifacial fanatics follow keenly.

Big60Million was renowned for its use of wildflowers to increase project biodiversity, returning land to former glory by welcoming pollinating insects. Gridserve turned once again to the same scientists, but with one added caveat; is there a species of pollinating plant that possesses high albedo properties? The answer, Harper says, is yes.

> "We are the evidence that's being created as opposed to being able to draw on somebody else"

Gridserve is remaining tight-lipped over precisely what that species is, but the science would suggest that planting them underneath rows of bifacial panels would contribute towards a performance boost, while simultaneously helping improve the site's biodiversity in what is unquestionably a win-win situation for sustainable solar.

Those plants will be tested, but if they grow successfully and do, indeed, deliver measurable increased gains for the bifacial panels resting above them, then Harper is adamant that it will create what is essentially an entirely new business case to plant and maintain acreages of such pollinators. It's just one contributing factor as to why he refers to the project itself as not just as a clean power station, but as an "ongoing R&D project at the same time".

When it comes to measuring the actual benefit of using bifacial panels over standard-issue, Harper says Gridserve has been reserved in its estimates. "I am optimistic that we have underestimated a number of factors, and something that we're particularly interested in is working at how we can optimise that bifacial gain," he says.

The difficulty for Gridserve, the company says, is that it is very much at the cutting edge of this deployment and cannot point to a precursor or similar case study for financiers to refer to. "We are the evidence that's being created as opposed to being able to draw on somebody else," he says.

What are perhaps more tangible are the fiscal benefits of employing trackers and batteries and making full use of that richly valuable export/import grid connection.

At the grid's service

Of the UK's ~13GWp of generating solar capacity, a significant majority is south facing, fitted on fixed mounts that produce the generation 'bell curve' the industry is all too familiar with. As the integration of renewables has grown, there have been burgeoning issues relating to supply and demand. Power produced in the middle

Credit: Gridserve

of the day is of less value and, following in the footsteps of other markets, the UK has witnessed prolonged instances of negative pricing in recent months.

Taking the same approach, as Harper frequently states, was not an option for this project.

By employing single-axis trackers – the first time the technology has been deployed in the UK – Harper says the company is giving the York project "broader shoulders", and shifting more of its peak performance into times of the day where its generation is of more value both to the grid and to the off-taker. While there may be a slight dip in performance around the usual midday peak, this is more than offset by producing more power than usual earlier and later in the day, when prices are steeper. In that sense, the trackers are performing a load-shifting role more commonly associated with battery storage.

That, handily, frees up the 30.4MWh of battery storage capacity co-located with the solar farm to derive revenue from other means, stacking on additional streams that help with the project's business case. The project stands ready to bid into UK electricity system operator National Grid's frequency reserve markets, including Fast Frequency Response (FFR), the Balancing Mechanism and the Capacity Market. It is also able to deliver reactive power services, critical at maintaining voltage levels on the UK's transmission grid, an area of works which is quickly rising in importance as more variable generation comes onstream.

But Gridserve also has eyes on those negative pricing periods, wherein the project's batteries can effectively be paid to draw energy from the grid, store it, then get paid again to discharge when the supply/demand metric has been flipped on its head. This is made possible by the import/export connection agreed with distribution network operator Northern Powergrid and stems once again from Gridserve examining the bare bones of a solar project and calculating how to optimise each and every cost.

Milking every last drop

More traditional solar farms in the UK might use their grid connection's maximum capacity for somewhere around 15% of the time, Harper says, meaning that for more than 85% of the time, that value is standing idle. "[Your grid connection] is one of the most expensive pieces of the project, which is where you derive 100% of your income, and you use that for a fraction of its time. That's not very clever," he says.

Adding the value of those grid-related services to its energy generation has meant that calculating project returns has been complicated, with Harper arguing that as projects become more sophisticated, the standard form of assessing their fiscal benefit becomes irrelevant. "You almost have to rip up the rulebook," he says. "We've spent a lot of time in the past working out things like levelised cost of energy (LCOE), but LCOE doesn't really make sense anymore in the context of all the additional revenue streams that projects like this can generate, many of which are completely independent to solar, so don't logically fit into LCOE calculations."

Nevertheless, in the weeks since York's switch-on, the site has surpassed expectations for what a solar farm might be able to produce in the north of England as autumn turns to winter. "So far the results are very encouraging and the amount of energy we're producing is impressive for this time of year," Harper says.

Despite the technological innovations, Gridserve's intent was always to under-promise and over-deliver, which is why the expectations of performance gains from bifaciality, trackers and additional revenue streams were reserved when the business case was put together.

Next on Gridserve's agenda is York's twin site, located a little more than 30 miles away in Hull, on England's north-east coast. That site is slightly smaller at 25.7MW, but it stands to pack just as much of a punch in terms of clean power per pound spent. When complete, both projects will transfer to Warrington Borough Council's ownership, who will pay around £62.3 million for the duo.

In combining new technologies with a detailed, holistic approach to energy generation and management, Gridserve is professing to have ripped up the rulebook for post-subsidy solar developments. If the intent of the York project was to move the needle forward somewhat, the company has certainly proven to do just that. ■

Product reviews

Inverter | Delta's M70A string inverter gives partial shade performance boost

Product Outline: Delta has launched the new M70A string inverter in Europe. The M70A's (77 kVA maximum power) six MPP trackers help planners configure large, complex PV systems. They also boost output from arrays that experience partial shade.

Problem: Commercial rooftop installations can be difficult to design due to partial shading obstacles. There is a need for string inverters to be able to maximise output from arrays that experience partial shade and provide greater flexibility to designers to optimise rooftop utilisation.

Solution: The M70A's six MPP trackers offer three pairs of connectors each to provide more options when arranging module strings. Planners can compensate for shading and complex roof geometries by allocating the MPP trackers accordingly. If two strings are attached per DC input, neither external string breakers nor fuses are required. Additional advances include an I-V curve feature for PV curve recording, Q at Night to supply reactive power to the grid outside standard feed-in periods, and Anti-PID (potential-induced degradation) to protect solar modules from the effects of voltage, heat and humidity.

Applications: Commercial rooftop installations ranging from 70kW to several megawatts.

Platform: The M70A also ships with an RS485 interface and wireless communications. This connectivity allows operators to monitor their M70As from the MyDeltaSolar Cloud with a smartphone app. The M70A mounts upright on a roof or base on the ground. It can also mount to a wall with the included mounting brackets.

Availability: Available since October 2019.

Battery | E22 vanadium battery storage system offers long-life and operational flexibility

Product Outline: E22 (Energy Storage Solutions), part of Gransolar Group, has launched its VRFB (vanadium redox flow battery) P50 and P250 containerised energy storage systems that are totally parallelable with a power and capacity of 50kW/200kWh (standard) and 250kW/1000kWh, and with expandable capacity depending on the size of the tanks.

Problem: Most battery solutions are designed to be oversized to cover lifetime degradation and ensure available capacity and power throughout the life of the system. Moreover, cyclability is very limited in some battery solutions and degradation is very dependable on the number of cycles and depth of discharge of each cycle.

Solution: The VRFB, P50 and P250 containerised energy storage systems offer product life exceeding 10,000 cycles at full power and 100% depth of discharge, resulting in an operational life greater than 20 years for most components, according to the company. Operation can be at partial states of charge (SOC) that have no impact on life, allowing effective upward and downward ramp control. The system comes with an islanding mode that is ideal for microgrid applications.

Applications: Integrated operation with renewable energy generation. Demand charge management. Diesel offset. Peak shaving. Energy shifting. Microgrid and back-up power.

Platform: The VRFB, P50 and P250 systems are a turnkey package in a secured weatherproof enclosure. It comes fully packed in a standard 20-foot container and includes Remote Diagnostic and Continuous Monitoring of all parameters, including the SOC. Low component count and robust design yield very high availability and low maintenance costs.

Availability: From Q4 2019, worldwide.

Inverter | Ginlong's Solis 125kW 1500V three-phase string inverter has 33% higher DC string voltage than 1,000V systems

Product Outline: Ginlong Technologies has expanded its Solis portfolio with a new utility-scale solution for the US solar market. The Solis 125kW 1,500V three-phase string inverter offers higher energy density and lower installation costs.

Problem: PV asset owners are increasingly turning to string inverter technologies for utility-scale projects that are intended to deliver substantial energy harvest advantages, compared to central inverters.

Solution: The Solis-125K-EHV-5G three-phase series string inverter have a maximum of 20 strings input, supports 1.5 DC/AC inverter load ratio and higher generation efficiency. The 20 DC inputs results in DC to AC ratios up to 150% for greater energy generation during lower irradiance conditions. Maximum efficiency is up to 99.00%. High system reliability means ultra-low maintenance costs, boosting returns over the life of the PV system assets. The Solis 125kW features built-in string monitoring, which measures all string parameters for quick fault isolation and system commissioning. An integrated smart I/V curve scanning feature helps detect such string faults as panel mismatch and shading, decreasing O&M time and increasing system energy yield. DC fuses on both positive and negative inputs protect the inverter and DC cables, while built-in replicable DC and AC Type II surge protection devices (SPD) safeguard during power surges, further ensuring system availability.

Applications: PV power plants.

Platform: The Solis-125K-EHV-5G has a touch-safe DC Fuse holders that adds convenience and safety. An optional AC combiner connects two 125kW units into a 250kW system, reducing AC cable costs. Type I SPD protection is also available to shield against damage from frequent surges and lightning strikes.w

Availability: September 2019, onwards.

Product reviews

Module | JinkoSolar's 'Tiger' module can generate up to 460Wp of power output

Product Outline: JinkoSolar is launching the 'Tiger' PV module series with a conversion efficiency of 20.78% and up to 460Wp of power output, which is suitable for both utility-scale and rooftop markets, globally. The Tiger module series will be available in both mono and bifacial options.

Problem: The global PV market is rapidly shifting towards high-performance modules to reduce system costs. Customers demand high power output and high efficiency modules to save on initial upfront capital investment. In addition, considering the energy gain from bifacial modules coupled to single-axis trackers, project owners can significantly lower the LCOE (levelised cost of electricity) as the downstream PV market becomes subsidy free.

Solution: The new Tiger module combines the half-cut cell design to reduce cell current mismatch and ribbon power losses. In addition, nine-busbar technology and tiling ribbon technology reduces the distance between the main busbar and finger grid lines, which decreases the resistance loss and increases power output and efficiency of the module.

Applications: Utility-scale PV and DG markets.

Platform: The Tiger series has several different options for both utility-scale projects and the DG market. The mono-facial Tiger module has a power output up to 460Wp from a module efficiency of 20.78%. In addition, JinkoSolar has also a small type mono-facial Tiger with a power output of 390Wp. For the DG market, JinkoSolar can produce an all-black series to further enhance the design's aesthetics. The bifacial Tiger module will be available with a power output of 455Wp and a module conversion efficiency of 20.06%.

Availability: In the first half of 2020.

Inverter | KACO includes silicon carbide semiconductors to new string inverters

Product Outline: KACO new energy has added five new string inverters to its product range. With outputs between 87 and 150 kilowatts, they are suitable for PV systems on commercial and industrial roofs as well as for ground-mounted solar parks.

Problem: PV inverters are the leading source of corrective maintenance activity in PV power plants, while the number one driver of PV project profitability.

Solution: The inverters are based on the technology of the blueplanet 125 TL3 which the Germany-based company introduced at the end of 2018. The advantages are mainly due to novel semiconductor components made of silicon carbide (SiC). SiC has more favourable thermal properties than silicon: power derating at high ambient temperatures only begins at a few degrees above +50 °C. The lower heat generation of SiC means that a smaller heat sink is used. Thanks to material savings such as these, the inverters have a weight of less than 80 kilograms which makes them comparatively light. The blueplanet 150 TL3 in particular has a power density of almost two kilowatts per kilogram.

Applications: The blueplanet 87.0 TL3 and blueplanet 92.0 TL3 are suitable for solar power plants on commercial and industrial roofs. New inverters with 110, 137 and 150 kilowatts of output are available to planners and builders of large, utility-scale solar power plants.

Platform: Since 1,500V technology is an emerging trend in the solar roof sector, both the blueplanet 87.0 TL3 and blueplanet 92.0 TL3 inverters are also suitable for solar modules with 1,000 Volts. The blueplanet 92.0 TL3 features a nominal AC voltage of 400 Volts: it can therefore be connected to the low-voltage distribution system without a transformer.

Availability: November 2019, onwards.

O&M | Kaiserwetter offers real-time benchmarking analysis of PV power plants

Product Outline: Kaiserwetter Energy Asset Management has added an advanced renewable energy benchmarking feature to the company's IoT platform ARISTOTELES. PV power plant asset managers can have their entire portfolios benchmarked, which they can then use to compare against their peers who have also opted in to having their data used anonymously.

Problem: According to information by the World Bank, roughly €1.5 trillion would have to be invested in renewable energies on a global scale to meet the Paris Climate Agreement. Large investments in renewable energies won't be made globally unless investment risks have been minimised and returns have been maximised, leading to the need to reach the highest possible standards of transparency with operating PV power plants.

Solution: Developed in partnership with SAP, ARISTOTELES turns complex and unstructured technical, financial and meteorological data into actionable, real-time intelligence for investors and financial institutions to minimise investment risks and maximise monetary returns. The new feature allows users to determine which type of solar panel should be installed in a particular location; define realistic performance targets; identify asset underperformance; evaluate operating and investment strategies; and understand the likelihood of different performance or reliability scenarios.

Applications: Benchmarking PV power plants.

Platform: ARISTOTELES aggregates PV power plant data anonymously to maintain confidentiality, and customers can upload their data to the database. The development of the database is focused on data from onshore wind farms and solar parks but will be extended to more types of renewables projects such as biogas, biomass, hydro and geothermal plants.

Availability: Currently available.

Tracker | NEXTracker's 'NX Gemini' tracker supports up to 120 modules on four 1500-volt strings

Product Outline: NEXTracker has introduced its smart single-axis solar tracker family, 'NX Gemini', which enables two-module-in-portrait (2P) tracking of either monofacial or bifacial PV modules.

Problem: Bifacial modules are rapidly being adopted for utility-scale PV power plant projects due to the higher power output, compared to monofacial modules in almost all ground conditions. To fully take advantage of bifacial module performance there is a growing need for balance of systems (BOS) configurations, such as trackers, to be highly optimised to provide the lowest levelised cost of electricity.

Solution: NX Gemini's 2P architecture results in shorter overall row lengths for design flexibility and contiguous solar panels for maximum array density. NX Gemini supports up to four 1,500V strings and requires only seven foundation posts for typical sites, delivering the industry's lowest number of foundations per megawatt. The 2P tracker features a patent-pending self-locking, multi-actuator distributed drive system for maximum stability in all wind conditions eliminating the need for dampers and producing virtually zero energy losses associated with stowing.

Applications: Utility-scale solar projects.

Platform: NX Gemini's installation-friendly array height and drive system allows module attachment on one side while the tracker is tilted, with the ability to rotate to complete the installation process on the opposite side. NX Gemini is backed by NEXTracker's global asset management and Digital O&M services, ensuring optimal performance and productivity over the lifetime of the system.

Availability: September 2019, onwards.

O&M | PVEL and Heliolytics providing disaster response service for solar power plants

Product Outline: PV Evolution Labs (PVEL) and Heliolytics have partnered to provide the first comprehensive testing and evaluation services to PV power plant owners and operators when extreme weather and other *force majeure* events have damaged plants.

Problem: The climate crisis has highlighted increased damage caused by stronger hurricanes and tornadoes that have also impacted critical infrastructure such as electricity generation, increasingly provided by PV power plants around the world. To empirically assess the real impact of storms on operating assets and process claims, insurance providers need new tools like Incident Response

Solution: The new service from PVEL and Heliolytics is intended to help solar asset owners and managers, operations and maintenance providers, investors and insurers prepare for and respond to such natural disasters. The on-the-ground testing is to be carried out by PVEL – both for a pre-event baseline analysis of PV power plants as well as the critical stage after a major incident occurs. This can provide accurate and independent data and hands-on engineering support to transact on insurance claims and fully address system underperformance, post event, which could result in financial losses and a reduction in the useful life of the PV power plant.

Applications: PV power plants

Platform: Quantifying underperformance and mechanical damage caused by the event with aerial testing from Heliolytics and on-the-ground testing from PVEL. Thermography and EL testing will be a key part of revealing and measuring underlying faults.

Availability: Available since September 2019.

O&M | SenseHawk provides integrated AI-powered software for PV power plant lifecycle

Product Outline: SenseHawk has launched three new applications to 'SenseHawk Core', its cloud-based platform for PV power plants. The three new applications are 'SenseHawk App' for site operations and collaboration, 'SenseHawk Desk' for ticketing and workflow management, and 'SenseHawk Vault' for file storage, indexing and sharing.

Problem: In the past, field workers have had to struggle with old-fashioned pen and paper or standalone apps with limited functionality and cumbersome data-entry interfaces.

Solution: The SenseHawk App is designed to enhance efficiency in site operations, bringing intuitive navigation, automated site status updates, one-touch ticketing, simplified task management, checklists and other information to site personnel throughout construction and operation. SenseHawk Desk enables tickets and checklists that are linked to elements on PV power plants of any size. It works for the full site, region, or inverter block and down to a fuse box. Tickets and tasks can be linked to any physical or logical element on site that can be assigned as a priority or track history. SenseHawk Vault is built on a digital model of a site. To find a spec or a drawing, clicking on the component on the map means access to all related files.

Applications: PV power plants.

Platform: SenseHawk Core is an integrated set of applications to support everything from solar plant design and construction to operation and maintenance. Using AI analytics, SenseHawk Core applications use this data and deliver actionable insights to support key processes and decisions throughout the solar lifecycle.

Availability: All six applications in SenseHawk Core are available now and offered individually or as an integrated solution.

Tracker | STI Norland's fourth-gen tracker handles rough terrain

Product Outline: STI Norland has launched the fourth generation of its 'STI-H250' tracker, the world's first two-wire solar tracker that handles complicated topographies and irregular plant designs.

Problem: Typical solar tracker systems are difficult to deploy with PV power plant projects located with high levels of changes in the slope or the contour of the land.

Solution: The STI-H250 solar tracker consists of two torsion beams placed in a north-south direction on which the photovoltaic modules are mounted. The two torsion beams are joined by a connecting rod and rotate

simultaneously following the sun's path. They are moved by a single engine, saving supply and maintenance costs. In addition, the fourth generation of the STI-H250 considerably increases adaptability to complicated topographies and irregular plant designs. The tracking control system is programmed with an astronomical calculation algorithm of the solar path. It includes Backtracking mode to avoid the generation of shadows between adjacent rows that improves production by up to 5%, as well as the flagging function to protect the follower in extreme wind situations.

Applications: Single-axis trackers for PV power plants.

Platform: The STI-H250 has a rotation range of +/- 55º, specially designed for projects where the orography presents important changes of slope or the contour of the plot is very irregular. PV module cleaning can be optimised by placing each row in the desired position, thereby achieving simultaneous panel cleaning on adjacent followers. In addition, the spaces between followers are passable for vehicles. This follower adapts to irregular implantations taking full advantage of the available land area.

Availability: September 2019, onwards.

Design | Terabase Energy's software platform is designed to cut PV power plant costs and inefficiencies

Product Outline: Terabase Energy has launched its web-based 'Terabase Platform' tool to accelerate development decision-making from siting through to design optimisation of PV power plants. It features integrated GIS layers and preset technology configurations and will auto-generate several project designs.

Problem: In today's competitive utility-scale energy market developers are challenged to deliver projects with ever-declining, record low-priced power contracts. The price of large scale solar has fallen by more than 88% over the last decade largely driven by improved scale economies for major equipment, like

solar panels. During this same period however, soft costs for activities such as engineering, site investigations, and field construction have not changed to the same degree. As a result, soft costs today represent about half of the cost of a solar project.

Solution: Unique to Terabase Energy's offering is its combination of software, data and proprietary tools allowing developers and EPCs to dramatically reduce project development and deployment costs and timelines. Terabase's ambition is to reduce soft costs by 25% over the next four years.

Applications: PV power plants.

Platform: Terabase utilises GIS design tools, AI-enabled consulting & engineering services, and inventory tags that track the location and fidelity of all components.

Availability: September 2019, onwards.

Module | Vikram Solar launches high-performance bifacial half-cut cell PV module

Product Outline: Vikram Solar has introduced its first bifacial module, featuring half-cut cells with the power up to 425 watts and a 27-year linear power warranty. The 'SOMERA' Series is also available in both glass-glass and glass with transparent backsheet architecture.

Problem: The energy gain from bifacial modules can significantly lower the LCOE (of PV power plants. High reliability, especially in tough environmental conditions are required of both glass-glass and glass with transparent backsheet bifacial modules.

Solution: The SOMERA Series uses half-cell mono PERC (Passivated Emitter Rear Cell) technology. Half-cells generate only half

the current of standard cells, which lowers heat generation and increases reliability and production. Yet the manufacturing process for the half-cells adds little to the product cost. The module's technological advancements include a high-performance encapsulation which optimises internal reflection and allows the module to harvest more light; lower interconnect resistance between cells, which minimises power losses; and the use of three split junction boxes with individual bypass diodes to reduce internal resistance and improve heat dissipation.

Applications: Commercial rooftops and utility-scale PV power plants.

Platform: The SOMERA modules' power ranges from 405Wp to 425Wp. The glass-glass design is ideal for environments with fluctuating temperatures and snowy winters. It is also perfectly suited for high-moisture environments such as floating solar energy systems. The series is also available with DuPont Tedlar-based transparent backsheet material. Vikram Solar was named a top performer in PVEL's 2019 Reliability Scorecard on the Damp Heat, Dynamic Mechanical Load Sequence, and Potential-Induced Degradation (PID) tests.

Availability: Beginning of 2020.

Influences of different backsheets on PV module durability in high-humidity environments

Module durability | Different types of PV backsheet provide modules with varying levels of protection in warm, humid conditions. Haidan Gong, Minge Gao and Yiwei of Wuxi Suntech's PV test centre detail the results of research undertaken to better understand the properties of different backsheet materials in tropical conditions

As the most commonly used encapsulating materials, ethylene-vinyl acetate (EVA) and polymer backsheets play important roles in module performance by providing protection against environmental exposure. Although cured, EVA will still undergo hydrolysis when exposed to heat and moisture, leading to formation of acetic acid. The failure mechanism of modules under damp-heat conditions has been studied in other literatures [1, 2] [1, 2]. The acetic acid reacted with lead oxide and formed lead acetate, which can cause power degradation of the module. Most polymer backsheets cannot completely block the water ingress into the module. Therefore, the water vapor transmission rate (WVTR) of the backsheet is crucial to the module power degradation in a high-humidity environment. In the past, there were two different points of view. One was that a backsheet with a low WVTR should be used to obstruct moisture ingress as much as possible to inhibit the hydrolysis reaction of EVA. Another was that a breathable backsheet was preferable, meaning that the water can easily ingress into the backsheet but also that the acetic-acid gas also can easily release from the module.

At present, there is no definite conclusion about the WVTR selection of backsheets in tropical areas. Most research has focused on the durability of the backsheet itself and payed little attention to the influences of the backsheet's water barrier properties on module durability. In this work, three aspects are discussed: module performance using backsheet with different WVTR, module performance using EVA with different VA contents and correlation between damp heat accelerated ageing and applications in high-humidity environments.

Experiment section

Four types of commercialised backsheet were used including: glass (backsheet 1), KPO (backsheet 2), CPC (backsheet 3) and PPf (backsheet 4). Silicon-based PV modules incorporating these four different backsheets were produced, using the same manufacturing process. One special module without a backsheet was also produced. Initial stabilisation was undertaken and then modules were exposed to 85°C ambient temperature and 85% relative humidity as described in the IEC 61215 standard. Every 1,000 hours, the electrical performance of modules was tested.

EVA with two different VA contents (28% and 32%) were used. VA content was measured using chemical titration method with NaOH. The FTIR spectra were measured using a Thermal Fisher Nicolet iS50 equipment.

Results and discussion

Module performance using backsheet with different WVTR

External influences such as water and oxygen normally can penetrate a backsheet and go into modules as shown in Figure 1. As mentioned before, moisture in the modules can lead to cell corrosion. So, the water vapor transmission property of backsheet is crucial to module reliability and durability.

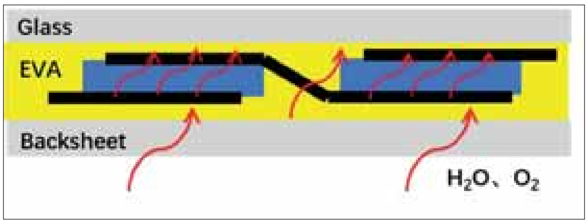


Figure 1: Water and oxygen penetration into module

	A	B	C	D	E
WVTR (g/m2•d)	0 (glass)	1.25	2.34	3.30	∞ (no backsheet)

Table 1: Modules using backsheets with different WVTR

Here, five groups of modules were produced under the same conditions (as shown in Table 1). Groups A to D used four types of backsheet with different WVTR and Group E were special modules without backsheets, meaning that the water vapor could totally ingress into the backsheet and the acetic-acid gas also could easily release from the modules.

These modules went through damp heat ageing for up to 4,000 hours and the module power loss was shown in Figure 2. It is clear that with increasing damp-heat time, modules using different backsheets showed different power losses. After DH 4,000h, modules using backsheet WVTR in the range of 0-4.0 g/m2•d (Group A to Group D), the power degradation increased linearly with increasing WVTR in a humid environment (as shown in Figure 3). The modules completely blocking water (backsheet A) showed limited power loss because these modules prevent the cell corrosion from acetic acid. The EL pictures after damp heat ageing are also shown in Table 2. The cell and ribbon corrosion conditions correspond to the power loss.

Interestingly, the modules without backsheet (Group E) showed low power degradation, and almost no cell or ribbon corrosion could be observed after 3,000h DH testing. But those modules showed large power degradation and obvious cell and ribbon corrosion after 4,000h DH testing. For modules without backsheet, in the first 3,000 hours of DH testing, the hydrolysis reaction of the EVA mainly occurred on the rear side of the module; the acetic-acid gas could also easily release from the module. But in the last 1,000 hours of DH testing, the water vapor penetrated

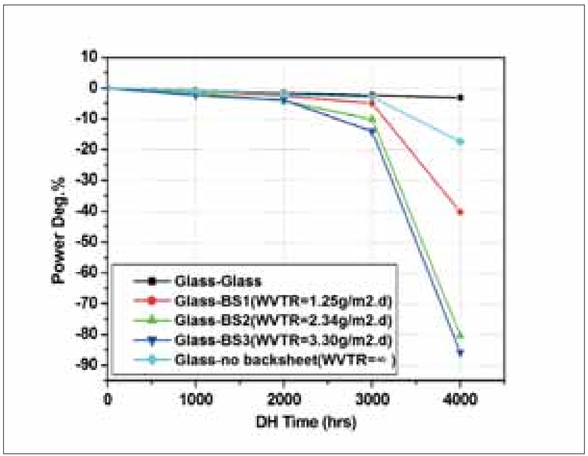


Figure 2. Power loss of modules different backsheets after DH

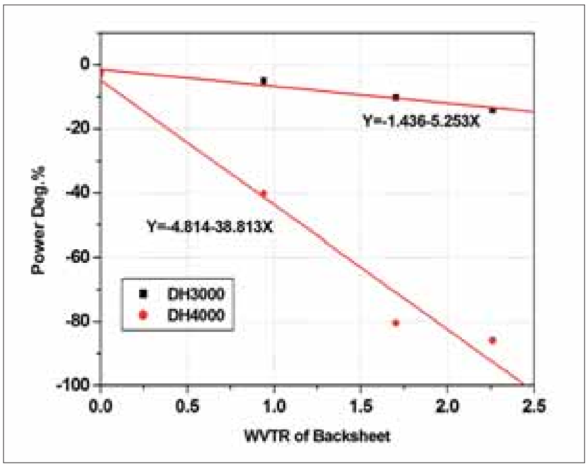


Figure 3. Power degradation vs. WVTR of backsheet

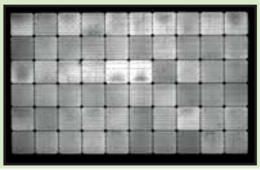
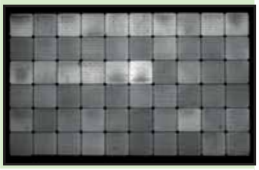
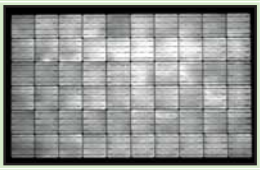
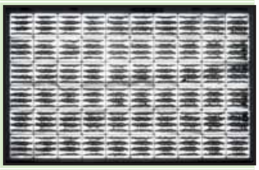
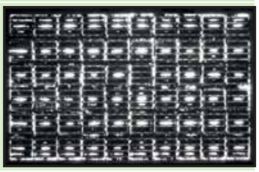
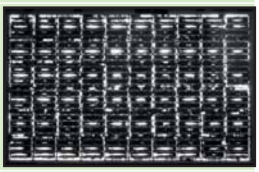
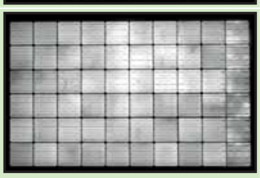
Group	After DH3000	After DH4000
A		
B		
C		
D		
E		

Table 2: EL pictures of modules with different backsheets after DH

the cell and ingressed into front side of the module, hydrolysis reaction of front side EVA is inevitable and the acetic-acid gas can't easily release through the cell.

Module performance using EVA with different VA content

The VA content is also a key value which affects the quality of EVA. In addition, the ester group will hydrolyse in a humid environment. EVA with 28% and 32% VA content were used in modules to see how they would perform in a humid environment. As shown in Figure 4, after DH 2,000h, modules using high VA-content EVA showed higher power degradation and more severe cell and ribbon corrosion. In Figure 5, modules with a higher VA content showed more cell corrosion after damp heat. This result corresponds to the power degradation results in Figure 4.

Correlation between damp heat accelerated ageing and applications in high humidity environment

In the natural environment, temperature, humidity and light are the three main factors that affect the reliability and durability of modules.

In order to predict a product's lifetime in real applications, several accelerated ageing models have been created and the Arrhenius model is the most known. In a high humidity environment, temperature and humidity play the major role in module ageing. Combining temperature and humidity factors, the Hallberg-Peck model[3] is commonly used to predict the ageing process in a high-humidity environment. The Hallberg-Peck model equation is as follows:

$$AF = \left(\frac{RH_t}{RH_u}\right)^3 \times e^{\left(\frac{E_a}{K}\right)\times\left(\frac{1}{T_u}-\frac{1}{T_t}\right)} \ldots\ldots\ldots eq1$$

T_u -1/T_t))………eq1

AF: accelerated factor

Ea: activation energy of this failure mode

K: boltzmann constant

Tu: absolute temperature under usage

Tt: absolute temperature under test

RHu: relative humidity under usage

RHt: relative humidity under test

Exceeded ageing time = Desired lifetime/ AF ...eq2

In the Hallberg-Peck model, the exceeded ageing time is related to the temperatrue and humidity in the application area as well as the activation energy of the modules' failure mode. The activation energy of the modules' failure is a the key parameter in

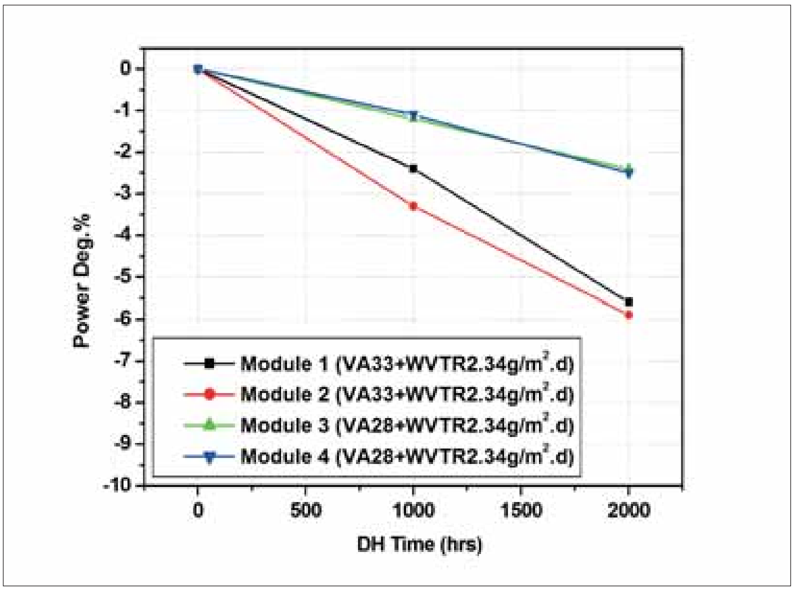


Figure 4. Power loss of modules using different EVA after DH testing

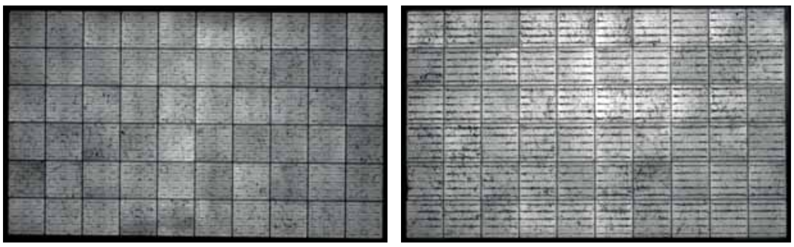


Figure 5. EL pictures of modules using different EVA after DH testing

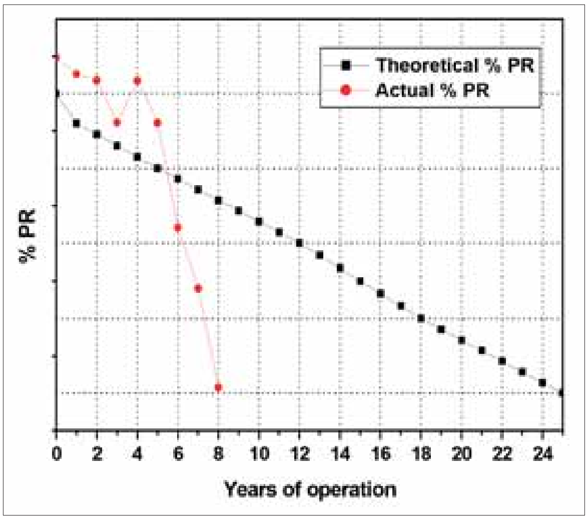


Figure 6. Actual PR degradation case installed in Southeast Asia

this model and usually it is an empiric value. Three real cases were studied to obtain the activation energy of this failure mode.

Case 1: modules installed in Southeast Asia in March 2012; average environmental temperature, 28.2°C, and average relative humidity, 61.8%. As shown in Figure 6, after only eight years operation, the PR of the whole PV plant show a high level of degradatio0n, close the theoretical degradation over 25 years.

Four modules were taken from the PV plant to measure the power output under a Class AAA pulse solar simulator. The results are shown in Table 3. It can be observed that the average power degradation of the modules encapsulated with BS WVTR 1.5 + VA33 EVA after eight years' operation is 28.5% and the average power degradation of the modules encapsulated with BS WVTR 1.5 + VA28 is 20%. We also took four modules from the warehouse, with the same encapsulation material and same production period (W32, 2011) as the modules from the PV plant, to receive 2,000h of damp heat testing. The results are shown in Table 4. It can be observed that there is a good correlation between 2,000h damp heat accelerated ageing and eight years of operation in a Southeast Asian tropical environment. The average power degradation of the modules encapsulated with BS WVTR 1.5 + VA33 EVA after 2,000h of damp heat testing is 26% and the average power degradation of the modules encapsulated with BS WVTR 1.5 + VA28 is 16%.

The electroluminescence (EL) after DH 2,000h showed similar appearances to the EL of modules aged in the Southeast Asian PV plant for eight years (Figure 7). Furthermore, Fourier-transform infrared spectroscopy (FTIR) was also applied to analyse the failure mechanism of the modules installed in the Southeast Asian PV plant and the modules after damp heat test (Figure 8). It was found that these modules have similar failure mechanisms. Lead acetate can be detected on the front side EVA. It is commonly believed that water vapor will penetrate into modules and lead to EVA hydrolysis. The resulting acetic acid will react with lead oxide in ribbons and cells. The formed lead acetate will cause resistance increases and cell darkening in EL. The difference is, lead acetate and peak EVA hydrolysis can't be detected on the rear side EVA in a failed module in the field. However, lead acetate and peak EVA hydrolysis can be detected on the rear side EVA of the module after damp heat testing. This result showed that the water vapor can ingress into the rear side of the module but also can diffuse to the outside through the backsheet in the field because the moisture concentration is different between inside and outside the module during day and night. When the water vapor penetrates a cell and ingresses into the front side of the module and can't easily diffuse through the cell, a hydrolysis reaction in front side EVA occurs. However, for the indoor ageing test, the water vapor will reach equilibrium both inside and outside the module during the whole ageing test, so the hydrolysis reaction of rear side EVA is inevitable.

Power degradation value, the EL images and FTIR showed that the indoor 2,000hrs of damp heat testing is equivalent to eight years operation in Thailand area. So according to the eq2, the AF is 35.04.

Case 2: modules installed on tropical Island A in 2012; average environmental temperature, 26.9°, and average relative humidity, 78.5%. As shown in Figure 9, only after six years' operation, the actual yield of electrical energy has 21.9% loss. In the EL image shown in Figure 10, cell corrosion also can be observed. Those modules are encapsulated with the BS WVTR 1.5 + VA33 EVA and BS WVTR 1.5 + VA28 EVA. According to Table 5, there is a good correlation between 2,000hrs damp heat accelerated ageing and six years of operation in the Island A environment. So according to the eq2, the AF is 26.28.

Case 3: modules installed on troprical Island B in 2013; average environmental temperature, is 27.2°C, and average relative humidity, 81.7%. As shown in Table 6, only after four years of operation, the actual yield of electrical energy shows a 17.6% loss. In the EL image shown in Figure 11, cell corrosion also can be observed. Those modules are encapsulated with the BS WVTR 1.5 and VA28 EVA. According to Table 4, there is a good correlation between the 2,000 hours of damp heat accelerated ageing and four years' operation in the Island B environment. So according to the eq2, the AF is 17.52.

Accoring to these three real cases, we can calculate the failure activation energy (Ea) of the failure mode in tropical areas; the related data are listed in Table 7. The Ea is about 0.425 to 0.482. Then we can use this

No.#	Pmax@initial	Pmax@after 8years	Deg.%	Material
1	294.2	200.9	32%	BS WVTR 1.5 + VA33 EVA
2	287.5	214.4	25%	
Avg. Deg.%			28.5%	
3	290.1	256.6	12%	BS WVTR 1.5 + VA28 EVA
4	291.3	209.9	28%	
Avg. Deg.%			20%	

Table 3. Power output of modules from Southeast Asia PV plant under class AAA pulse solar simulator

No.#	Pmax@initial	Pmax@DH1000	Pmax@DH2000	Deg.%@DH2000	Material
1	280.9	276.1	205.8	27%	BS WVTR 1.5 + VA33 EVA
2	278.5	277.0	208.1	25%	
Avg. Deg.%				26%	
3	213.6	206.4	188.4	12%	BS WVTR 1.5 + VA28 EVA
4	213.5	209.5	170.7	20%	
Avg. Deg.%				16%	

Table 4. Power output of modules from warehouse under class AAA pulse solar simulator

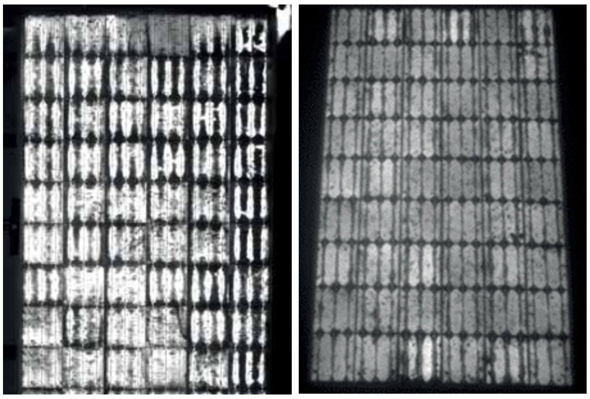


Figure 7. Left: module after installation in a high-humidity area for eight years; right: module after DH 2,000 hours

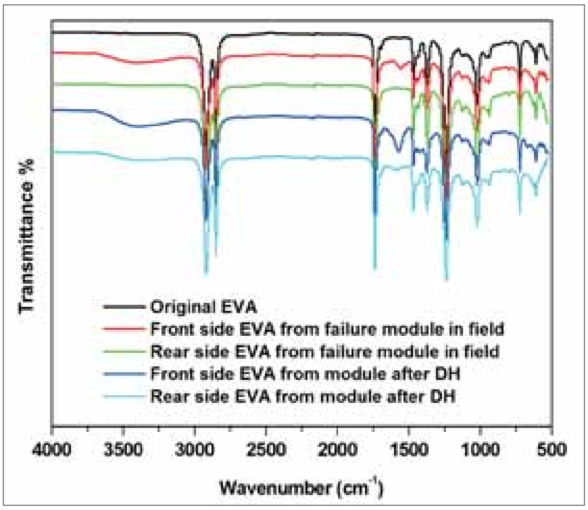


Figure 8. FTIR spectra of EVA from modules in field and after DH

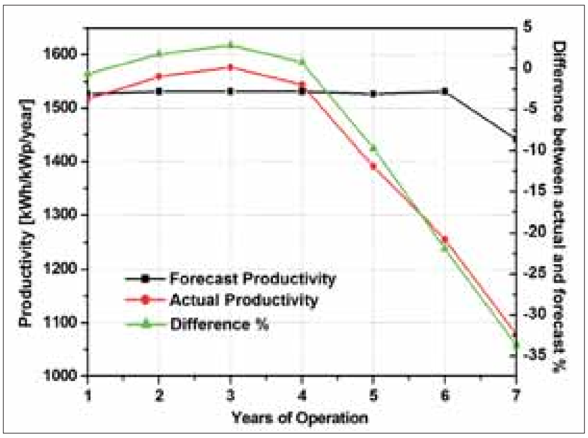


Figure 9. Actual PR degradation of modules installed on Island A

Figure 10. Module after installation on Island A for six years

No.#	Pmax@initial	Pmax@after 6years	Deg.%	Material
1	245.8	178.2	27%	BS WVTR 1.5 + VA33 EVA
2	240.0	207.0	13.8%	BS WVTR 1.5 + VA28 EVA

Table 5. Power output of modules from Island A PV plant under class AAA pulse solar simulator

	2013	2014	2015	2016
Yield (KWh)	85	85	75	**70**
% Yield Loss			11.8%	**17.6%**

Table 6. Actual yield of electrical energy from modules on Island B

	Avg. Temperature (ºC)	Avg. Relative humidity (%)	AF	Calculated Ea (eV)
Southeast Asia solar plant	28.2	61.8	35.04	**0.425**
Island A solar plant	26.9	78.5	26.28	**0.482**
Island B solar plant	27.2	81.7	17.52	**0.440**

Table 7: The failure activation energy in tropical areas

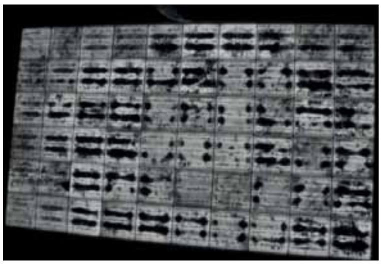


Figure 11. Module after installation on tropical Island B for four years

Ea and Hallberg-Peck model to calculate the different indoor extended damp heat testing time at different temperature and relative humidity area.

Conclusion

This work mainly focuses on the influence of backsheet WVTR on module performance in high-humidity environments. Theoretical modelling and field case data showed that long time damp heat accelerated ageing can simulate the module ageing pattern in a high-humidity field environment. Using the Hallberg-Peck model, the activation energy was calculated in areas with different temperatures and relative humidity. In addition, results showed that modules using backsheet WVTR in the range of 0-4.0 g/m2•d, the power degradation increased linearly with increasing backsheet WVTR in a humid environment. Finally, module performance using VA content 28% and 32% were compared. It was found that high VA content EVA will lead to higher power degradation and cell corrosion. ■

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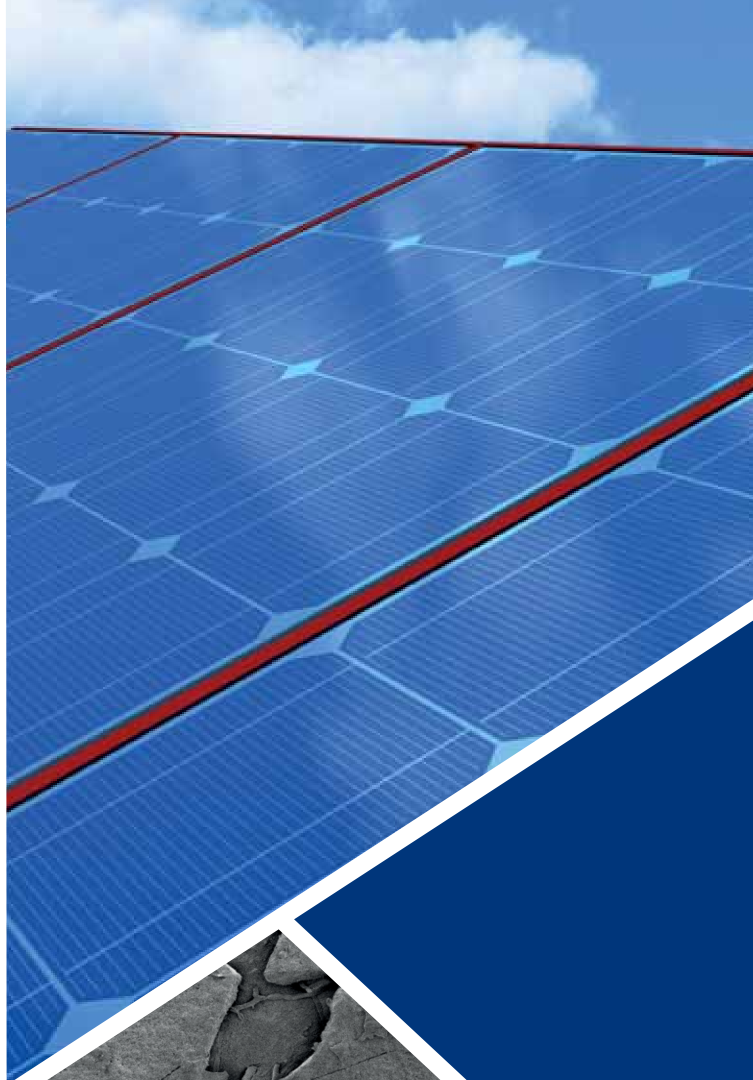

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Kynar® Film: Completely UV resistant protective film to build KPK® and KPf Backsheets

By Dr Samuel Devisme, Bernard Schlinquer, Sun Jia-Yue.

Kynar® PVDF in demanding applications:

Kynar® PVDF polymers have been used in very aggressive environments like oil and gas exploration for over 30 years. Kynar® PVDF is used in this market because of its excellent chemical resistance and ability to withstand and not degrade under high continuous use temperatures (130°C) and very high pressures. Kynar® PVDF is therefore recognized and specified by the major oil companies worldwide for pressure sheathing in high performance flexible offshore pipes.

Kynar® polymers are also used in the architectural market in coatings on metal and is specified by architects worldwide because it is virtually completely resistant to UV degradation. Metal panels coated with paints made from Kynar PVDF directly exposed to the sun in South Florida have not changed, eroded or discolored in over 50 years.

Naturally, when the photovoltaic market started to pick-up in the early 2000s, our customers requested that Arkema develop a Kynar® PVDF film suitable to bring 30+ years protection to UV and environmental erosion to the backside of photovoltaic panels.

Kynar® Film: pioneer in PVDF films for PV with its unique 3-layers structure

In 2001, Arkema launched its new and unique Kynar® Film product line, produced by a patented Multilayer Blown Technology, it was quickly evident that photovoltaic backsheets were in need of a durable protective film at least equivalent to the existing PVF film whose capacity was unable to cope with the growth of the solar industry. Thanks to its collaboration with Krempel GmbH and Arkema's experience with multilayer Kynar® PVDF films, Arkema was able to design a 3-layer PVDF film structure that has been unsurpassed in performance since then.

A worldwide recognized premium protective film

Since its introduction in 2006, module makers have come to realize that Kynar® Film based backsheets provide greater durability and longevity compared to all other backsheet products. Thanks to a wealth of very harsh and accelerated weathering results, customers quickly realized that our unique 3-layer film for PV backsheets was superior compared to any of the other incumbent films. In particular, its resistance to thermo-oxidation is far superior to many other fluoropolymer films (see below).

Kynar® PVDF Film is also the most UV resistant protective film. The first reason is that PVDF has the highest fluorine content compared with most competitive fluorinated Polymers (59% vs 41% for PVF). The second reason is that the film contains two pure PVDF skins which is the optimal way to take full advantage of the outstanding properties of Kynar® PVDF.

An unsurpassed track record

This impressive resistance under the most stringent conditions has convinced key module manufacturers to use Kynar® Film based backsheets. Since its launch in 2006, more than 20 GW of panels have been installed containing at least one layer of Kynar® Film protecting the back from any outside aggression. Field surveys after several years of usage have shown positive feedback both in term of real life backsheets ageing and electrical insulation integrity.

Why Backsheets are key to module durability?

Degradation of backsheet through insufficient resistance to environmental factors can result in the loss of electrical insulation of the module, with increased risk of current leakage and electrical arc formation. Therefore, materials for backsheets should be selected according to highest resistance to UV, abrasion, humidity, chemical resistance and a combination of those factors.

Kynar® Film is extremely resistant to sand erosion, has the highest thermal stability and coupled with its complete UV and chemical resistance, make it the ideal material to ensure that backsheets do not degrade in any way over the entire service life of the PV panel.

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KPK® and KPf Backsheets

Today there are many different types of backsheets being offered, even some other generic PVDF film based backsheet but don't be misled – you should request only genuine KPK® or KPf backsheets to make sure that you are getting a backsheet that contains our unique high performance Kynar® tri-layer protective film. To be sure it is the true KPK® or KPf backsheet, please request from Arkema the list of licensed, authorized suppliers.

KPK® Brand: Arkema makes sure that only suppliers using 100% of the original Kynar® Film Trilayer Films to produce two sided KPK® Backsheets are authorized to use this brand.

When you specify KPK® backsheets you are ensuring that both the inside and outside are protected by Kynar® Film. Protecting the inside of a backsheet with such unique resistance to thermo-oxidation, is very important in case of hot-spots. Encapsulants are letting more and more UV go through and a perfect UV resistance on the inside is essential to assure 25 years durability.

To learn more about Kynar® 3 layers film for KPK® Backsheets, please contact us:
In China: jia-yue.sun@arkema.com
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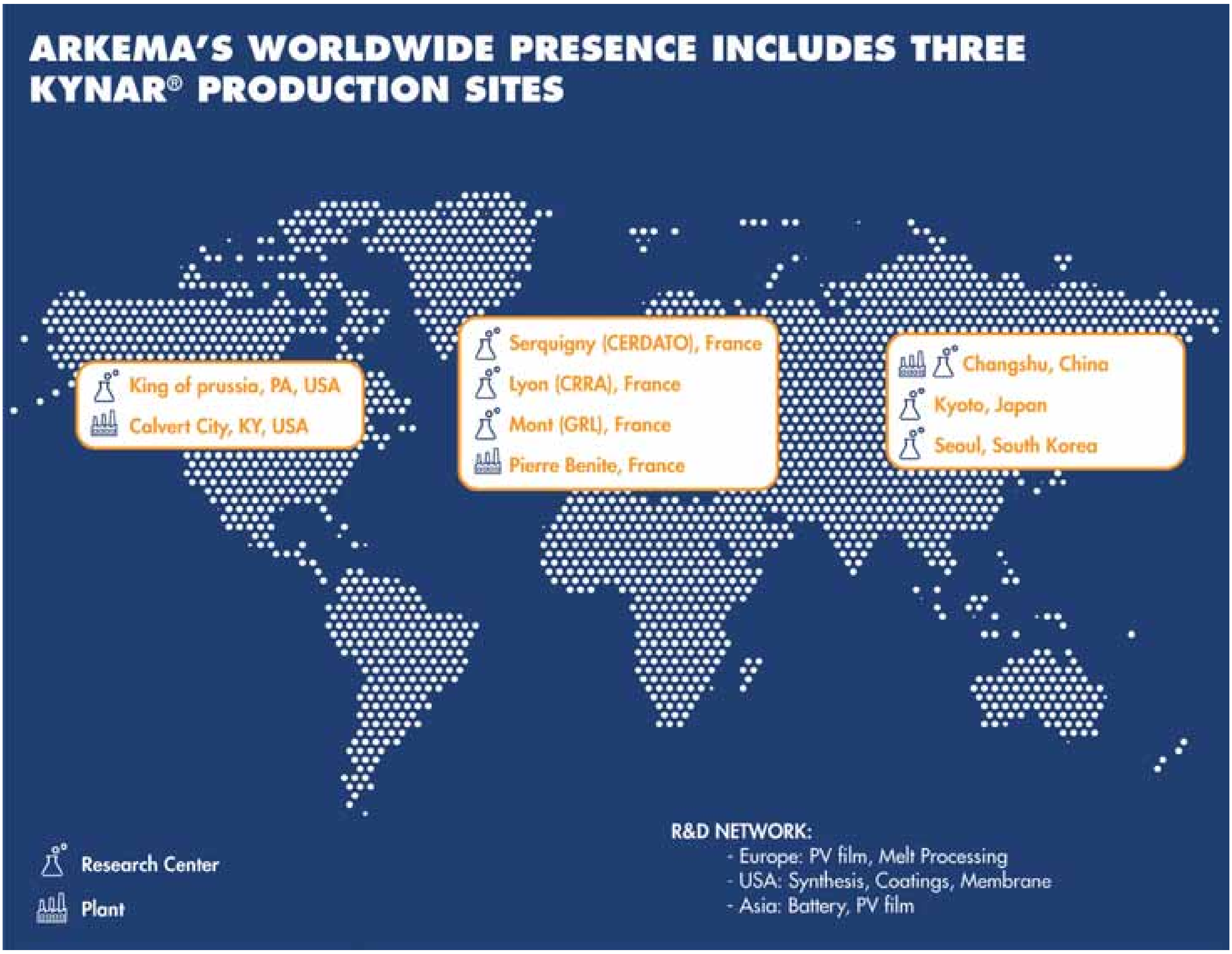


ARKEMA's worldwide presence includes three production sites to manufacture KYNAR®

O&M and asset management 2.0: optimising the sector through digitalisation

Operations & maintenance | New technologies are helping revolutionise the management and profitability of PV power plants. Martina Pianta, Guillermo Oviedo Hernández, Constantinos Peonides, Will Hitchcock and Máté Heisz look at some of the digital innovations helping advance the deployment solar energy in Europe and beyond

Credit: Above

The use of drones is just one of the innovations helping drive forward the sophistication of solar O&M and asset management

In a post-subsidy era and as assets increase in size, pressure on the lifecycle cost of utility-scale solar has intensified. From development through to operations and maintenance (O&M), it is widely accepted that the industry needs to embrace digitalisation and technology to increase efficiency and automation across all stages of the asset's life.

In order to meet the 2030 EU climate targets, member states are committed to increasing electricity generation from renewable resources. One of the most effective ways forward, from an ecological and economic point of view, involves improving the actual performance, and reducing the operational costs, of existing renewable power plants. An effective strategy for achieving this goal is the application of digitalisation techniques – including artificial intelligence (AI), data mining, drone operation and robotics – to convert the immense amount of data that these plants generate into information that can be used to make optimised operational decisions.

Data mining and AI are creating a smarter sector

The potential of data mining algorithms to optimise performance and reduce operational costs is widely demonstrated, provided that the data is of high quality and granularity, and is consistent, robust and processed within the proper system model framework. The impact of this approach to managing renewable portfolios goes beyond the immediate benefit of fully exploiting the capacity of the plant, and further facilitates an overall increase of profits (via a decrease in levelised cost of energy, LCOE), and the mitigation of certain operational risks. This will ultimately attract more investments – both for renewable projects and grid infrastructure – generating a virtuous circle that will trigger new capacity deployment and a higher penetration of renewables in the energy mix.

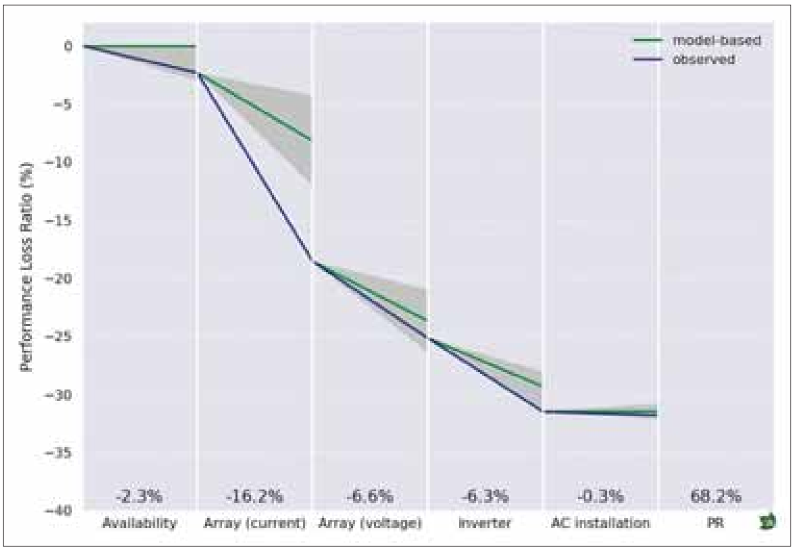
Predictive maintenance

Predictive maintenance through data mining consists in retrieving vast amounts of data from one or more sources and combining them with the aim of understanding ongoing anomalies and predicting the future behaviour of linked devices. Big data analytics can bring added value at any stage of asset management: from observation of collected information to fault detection, fault diagnosis and finally optimisation through recommendations. Today, different approaches are proposed. Whereas classic AI proposes advanced diagnostic through knowledge-based models, unsupervised and supervised learning methods offer different possibilities (e.g. neural networks) using statistical approaches.

The benefits of predictive maintenance include reducing plant losses and optimising plant performances. Exploiting high-frequency data sent from the site, combined with a detailed model of the installed system, can enable operators to analyse the plant's condition, leading to an immediate and effective decision that requires nearly no time. Thanks to current data-mining techniques, asset operators can easily make decisions on the most effective way of performing their daily operations and maintenance activities, improving the performance of the portfolio and anticipating failures of the devices composing these complex systems.

Predictive maintenance techniques have undergone rapid developments in recent years. Monitoring and performance platforms can combine independent monitoring and data collection with the most reliable performance analysis algorithms in the PV industry.

A carpet analysis of all available asset data, associated with a well-known set of parameters of the site and consistent algorithms, is used by advanced monitoring and automated diagnostics tools. These tools apply a full loss root



Credit: 3E

Figure 1. Modelled versus observed PR degradation in PV power plant

cause analysis based on the comparison of expected losses (the so-called "digital twin") and actual losses, for each conversion step. In this way, targeted recommendations for immediate or mid-term actions drive performance optimisation by a sensitive reduction of device downtime and underperformances. Additionally, a smoother planning of activities and a better device replacement scheduling reduce hardware and operational costs.

The waterfall diagram in Figure 1 is an example showing the PR degradation of one plant for each conversion step. In this case, the operator can easily focus his attention on the main event that creates the higher PR losses (in this case the DC current) and then drill down into the data to investigate the problem in further detail, understanding how long it has been occurring and evaluating possible root causes.

Cloud computing

The key to an effective management of renewable assets and portfolios consists in an easily accessible platform, built with open architecture, which enables users to receive, store and process data from different kinds of on-site devices and data from other varieties of external platforms.

Cloud computing serves this purpose by managing a large amount of data coming from on-site devices, and by collecting and sending information to and from the grid, relaying operational dispatching and contract management data in real time over the internet. Cloud computing is typically available online via most browsers and does not require the installation of local software, while computing resources are shared in a network.

Beyond the initial phase of configuration and customisation necessary to connect to the multiple data sources, cloud computing has the certain benefit of reducing all efforts in collecting and aggregating data to produce meaningful information for any user.

On-demand, scalable and accessible from any device with internet access, it serves as a communication and collaborative set of tools that ultimately reduces the cost of operations and enhances the efficiency of plant management.

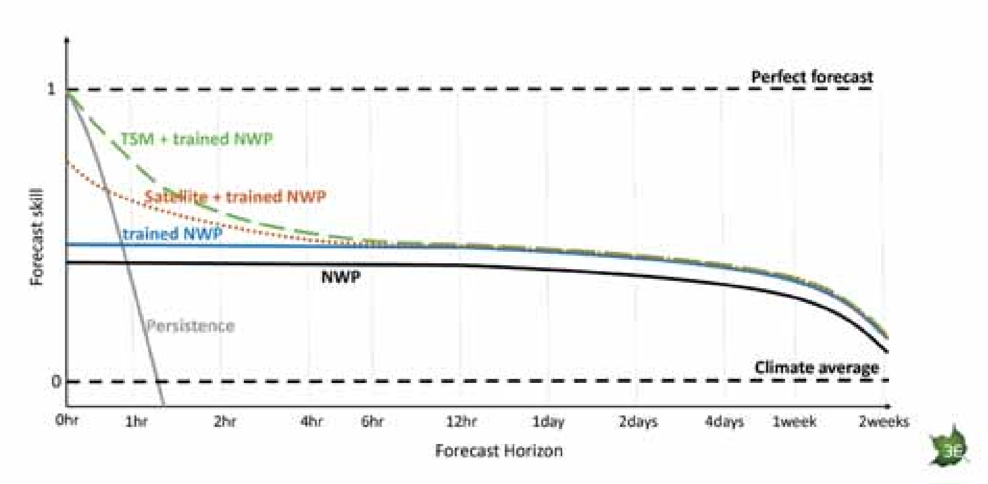
Combining these different data sources in a transparent and open way implies the need for interoperability. Modern portfolios rely on connecting and enabling the interaction between different devices, applications and services to serve their intrinsic diversification, paving the way for the creation of Platforms as a Service (PaaS).

PaaS encompass the advantages of cloud computing over different applications and serve as a unique interface layer for all underlying services around the photovoltaic business, from the operational to the administrative level.

Remote sensing and control

The share of renewable generation in the energy market is growing, expected to reach 30% of overall energy demand by 2030. The major challenge within this new composition is given by the unpredictability of energy availability, where an important lack or excess of energy would lead to a collapse of the grid and consecutive blackouts.

Detailed information from the site coupled with a precise model and accurate solar resource forecast allows for efficient



Credit: 3E

Figure 2. A combination of forecasts can lead to more precise results

prediction of the expected performance of a photovoltaic asset. By coupling this information with the expected need from the grid operator, an advanced monitoring system is capable of communicating to on-site devices the best operational behaviour to adopt to avoid grid stress.

Reaching a steady balance for the grid is the first benefit of this approach; however, the combination of remote sensing and control with a storage system (local or performed by an aggregator) allows for further advantages for the energy producer and end user. First, being able to store the energy when it is not manageable by the grid represents a better option than capping the PV plant output, or worse, shutting it down. Furthermore, the combination of energy price fluctuations and the ability to modulate the energy sent to the grid gives the energy producer the possibility of extracting the highest value from the energy produced.

Direct control of the plant by the DSO or an aggregator is one of the ways to manage the modulation of the produced power to fit to the grid capacity. Other techniques foresee the automatic derating of PV plants through full automation. However, this has not yet been fully implemented. In several EU countries, the regulation is heading in the direction of prediction of intraday and day-ahead production for a better power balance.

An increasing need for energy forecasting

In a context where renewables make up an important share of the energy market, one of the major challenges that the sector continues to face is energy management, which is complicated by the variability of renewable generation. The accurate forecasting of both load and production combined with sophisticated market pricing mechanisms (e.g. negative prices and negative control energy) can help the sector to overcome this difficulty. Further, it is important that operational insights (i.e. plant monitoring and O&M scheduling) are cultivated and disseminated so as to result in the best-in-class intra-day and day-ahead prediction of plant energy production.

Assessing the irradiation of a PV plant is crucial to successful operations. Depending on the time forecast horizon, a combination of forecasts based on Numerical Weather Prediction (NWP) models and advanced time-series models (TSM) can lead to precise results. Today, state-of-the-art technologies in this field can provide intra-hour to day-ahead forecasting with Mean Absolute Error (MAE) values ranging in the order of ±4% (normalised to the installed capacity of the PV plant), depending on region (weather conditions), and on-site data availability and quality as input for training algorithms.

The second important component of optimised forecasting is the estimation of plant performance given the irradiance conditions. A data mining tool, encompassing all plant boundary conditions – such as components datasheet, layout, installation date, components temperature, estimated degradation – would ultimately provide a consistent indication of forecasted energy. This would involve only a small uncertainty, in the order of ±2%, in the best-case scenario when all plant conditions are well known with high granularity details, and the information is updated at each moment by the O&M team.

A final component of uncertainty includes the unforeseeable events, such as grid unavailability or component failure, that would change the forecasted energy output with the most significant variance. Component failure can be somewhat foreseen with advanced data mining tools; however, the precision of these methods is highly dependent on information that the hardware can provide to the data mining tool. A standardisation of signals emitted by PV component devices would be required for an optimal and predictable system.

There are at least three advantages of such an energy forecasting system. First, this would result in optimised planning for O&M activities. Awareness of meteorological conditions and plant performance in advance, combined with forecasted energy pricing, would allow for an easier trade-off between switching off production and servicing the site. Second, energy forecasting allows for optimised storage needs by managing the charge and discharge of energy accumulators. Third, these tools allow the highest value of produced energy to be harnessed through an optimised energy trading intelligence. Through the proper usage of day-ahead and intra-day forecasting services, an operator can reduce transaction risks and effectively balance costs.

Field work of the future

In the present highly competitive PV sector, price pressure is forcing O&M contractors to increase plant performance and energy yield while minimising operation costs. To tackle this challenge, in markets where the full-time presence of technicians on-site is unaffordable, the adoption of digital solutions for the optimisation of field interventions is becoming an imperative.

Digital technologies are already providing great benefits in areas such as plant monitoring, asset management, yield forecasting and aerial thermographic inspections. Highly automatised control rooms are replacing time-consuming methods of spreadsheet-based calculations by advanced analytics and O&M-specific software, which, along with the use of AI engines, promise to enhance efficiency in dispatching.

But field operations have somehow lagged behind. State-of-the-art technologies barely go beyond assisted scheduling and remote support via email or telephone. Despite fully digital ticketing systems being in place, the daily activities of field workers have not changed much in the past decades. This becomes even more evident when troubleshooting activities force the allocation of valuable resources to solve urgent issues – for instance, by deploying highly qualified personnel on-site.

In the European market, we have seen an increase in the efficiency of technicians, not only due to increased education and up-skilling, but also thanks to the widespread use of IT technologies. However, in some regions where plants are small (e.g. 1MWp) and spread over a large territory, the number of technicians required to service the managed portfolio is still large. Furthermore, additional challenges may arise when dealing with old PV plants that have surpassed their mid-life point and are getting closer to end-of-life, where the deployment of state-of-the-art monitoring and SCADA systems is often not feasible (for obvious financial reasons) and therefore, field workers cannot always benefit from the innovations coming from modern IT.

Nevertheless, in the mid-term, for new large-scale portfolios, it is envisioned that field workers will fully benefit from more interconnected digital ecosystems. For example, IoT and industry 4.0 solutions will enable the digital recreation of PV plants (3D digital twins), where each single component will be geo-referenced and will become a fully manageable digital entity. In this landscape, a field technician equipped with a smart device (e.g. smartphone or tablet) will be able to locate the components of the plant that need maintenance or repair. Furthermore, just by selecting the component of interest on the screen, it will be possible to record (e.g. upload pictures) and document the operations performed. Then, that data would be automatically uploaded and categorised into a database, which will process and analyse it in order to support the decision-making process with indications of the necessary operations to be performed in terms of predictive maintenance. Additionally, solutions such as helmets powered by augmented reality will provide field workers with real time remote assistance by expert service engineers, who can guide them through specialised technical interventions without the need to be on site.

How drones help the sector to soar

Over the past few years, the use of drones in the solar industry has moved from a novelty to a mainstream technique. Initially seen as a gimmick with questionable value, drones are now fulfilling key roles across the entire asset life cycle.

In the early planning stages, the use of drones for topographical surveying provides a faster, lower cost and more useful output than that of traditional surveying techniques. Using either Lidar or photogrammetry, the drone can survey large areas quickly and accurately to assess the viability of potential installation sites. Drone topography accuracy is high, and the resulting shading model increases confidence in the yield calculation, thus resulting in more informed decision making.

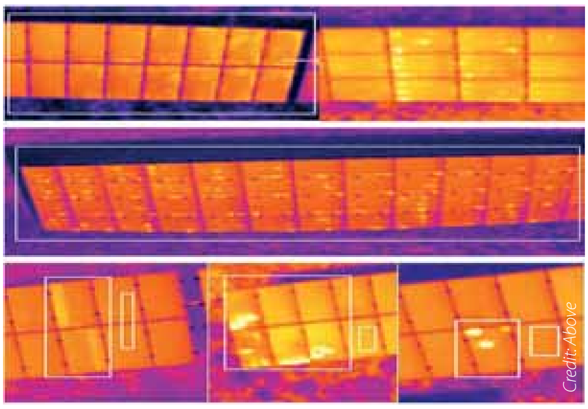


Figure 3. The detection of problems such as PID is just one of the many functions drones can perform in PV power plant management

During the construction phase, drones are used for construction monitoring, which, for larger assets, is a valuable addition to security and stock management as well as project status reporting. However, it is during the commissioning phase that the drone can add the most value – using photogrammetry, it is possible to produce a highly accurate 3D model of a solar asset. This not only generates detailed 'as-built' CAD drawings based on real-world data but can also be used to assess the asset's external, internal and self-shading profile to validate the reference yield calculation; a valuable addition to technical due diligence and vital when considering the reference yield's onward impact on the PR figure and its influence over commercial decision making.

The use of drones for thermal imaging has quickly become an industry standard. Drones are transforming the way in which technicians validate an asset's electrical integrity, in an industry previously reliant on manual string measurements and random ground-based thermography. Aerial thermography provides a complete picture of the asset down to a cellular level. This low-cost and highly accurate technique helps prevent early yield and revenue loss by identifying quality, construction and commissioning issues in their early stages. Thermal imaging conducted at PAC provides an early health baseline for all modules. In addition to a comprehensive plan for the EPC to resolve any identified issues ahead of IAC or FAC, when a second thermographic inspection should be conducted.

Advances in software allow for the integration of all types of aerial data with other inspection, testing and monitoring data to create a digital twin of the solar plant. This provides the industry with a robust platform to monitor plant health, chart degradation and manage issues. Early identification of issues and degradation leads to a faster response time, more efficient use of resources and, ultimately, a more productive and financially viable asset. Development in drone technology, sensors, AI and computer vision will continue to increase the value they bring to the solar sector, playing an important step in the journey to net-zero.

Lifecycle asset management can optimise solar projects

As the solar sector becomes increasingly globalised, with service expectations requiring cost reduction and revenue optimisation, asset managers are beginning to rely on advanced digital asset management platforms that enable efficient and effective management of diverse solar portfolios.

The asset manager is a key position in the solar power plant's lifecycle: from development, through construction and operation, to decommissioning and disposal. By focusing on the operational phase – the longest phase of the project lifecycle – it becomes clear that lifecycle project management is crucial to the success of solar projects.

Throughout the lifecycle of the solar plant the asset manager oversees a number of core competencies across technical, financial and contractual functions. Stage-gate management involves the asset manager ensuring that at transitions between milestones, the required documentation associated with risk management, value protection and performance is validated and stored. Documentation management requires the asset manager to ensure that an index mechanism exist for the storage, version control and retrieval of static and dynamic documents that underpin the value of the plant.

Risk management demands a comprehensive approach with the asset manager tracking key risks throughout all project phases. Asset managers are recommended to request the certification of power plants through their lifecycle to international standards via available international certification schemes or conformity assessment systems.

During the operational phase, the asset manager's responsibilities are myriad. EPC contractors usually provide a two-year performance warranty period after the commercial operation date (COD), during which it is the responsibility of the asset manager to monitor, calculate and report the values of Performance Ratio and other KPIs guaranteed by the EPC contractor. In this context, the asset manager is responsible for managing the interventions completed within the scope of the warranty in order to safeguard the performance commitments undertaken under the contract; informing the asset owner about the condition of the contracted performance indicators; and alerting the asset owner whenever the levels of the indicators have values or tendencies that could indicate a risk of failure. All these activities require the asset manager to pre-empt issues of equipment life expectancy through the effective management of an asset register.

Further, the management of data throughout the lifecycle can be facilitated by digital platforms. Asset managers should make use of an asset management platform that can undertake some or all the digital aspects in order to consolidate all relevant information. Advanced data analysis services come in many forms, with the most sophisticated using special algorithms including machine learning for exploring big data. Service providers with experience and knowledge in the solar industry can combine this with digital analytics to transform data into intelligence. The use of this software can help asset managers identify problem areas, as well as reduce costs through comprehensive plant data. Indeed, the act of plant monitoring itself is being increasingly automated, simplifying overall reporting documentation.

In all these cases, comprehensive lifecycle asset management in tandem with the latest digital service platforms can optimise all phases of development of the solar power plant.

Making a 'mark' on O&M and asset management

As the global energy landscape is changing, new rules and regulations are introduced and established. In this environment, the necessity emerged for operations & maintenance best practices guidelines, in order to standardise procedures across the board without geographical boundaries.

Since its inception in 2016, the O&M guide has evolved (already in its fourth version) into a comprehensive document, with each new version addressing the newest market trends and requirements. The main topics of the guidelines include environment, health and safety, training of personnel, plant operation and maintenance, revamping and repowering, data monitoring, and contracts.

To emphasise the importance and value of the guidelines, an O&M best practices 'mark' was developed. This is a self-assessed mark that O&M service providers can obtain by adhering to and following the guidelines. The mark is an indication of excellence, with two key benefits: (1) internally, as it is self-assessed, it helps organisations re-evaluate, re-engineer, and transform their processes in order to become more transparent and efficient; (2) externally, for asset owners looking to outsource O&M service activities, the mark helps them select the best third-party independent service providers.

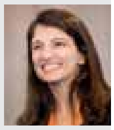
As the industry continues to evolve into a global marketplace, with investors showing greater interest in widely dispersed portfolios, it became clear that best practice guidelines were required for a role that is becoming more important across sectors: that of asset management. This role involves supervising O&M service providers and the quality of service they are delivering according to the contract and standards that they have agreed on with the asset owners, as well as adhering to all statutory legal tasks and other requirements that relate to the financial management of assets.

The first version of the "Asset Management Best Practice Guidelines" is currently being prepared. The document will outline the best practices of the industry and set a new global standard. As the PV sector becomes more and more globalised and decentralised, the need for standards such as these becomes more and more important.

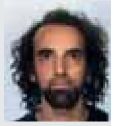
SolarPower Europe's O&M guide has a proven track record, helping the sector to ensure a high level of quality and consistency. The O&M best practices mark will provide further guidance to contractors, investors, asset managers and all interested stakeholders all over the world. The forthcoming asset management guidelines will fill a crucial gap, supporting the sector to deliver cutting-edge, cost-efficient and future-proof services that will allow solar to continue its growth trajectory.

With the European demand for solar increasing by 80% in 2019, adding 20.4GW of installations, and forecasted installations for 2020 currently sitting at 24.1GW, the EU remains a world-leader in the climate transition. SolarPower Europe is committed to providing clear O&M and asset management guidelines in order to support this very necessary growth.

Authors



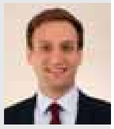
Martina Pianta is the product manager at 3E for SynaptiQ, a performance monitoring platform. Through SynaptiQ, she strives to help O&M and asset managers to reach plant performance excellence. Martina has more than 10 years of experience in the renewable energy sector and has been an active member of SolarPower Europe's O&M and Asset Management Task Force since 2016.



Guillermo Oviedo Hernández works for BayWa r.e. Operation Services S.r.l. since 2017, within the SOLAR-TRAIN project, which is a Marie Sklodowska Curie-Action funded by the European Union's H2020 programme. His professional path has taken him from computing engineering (bachelor's degree) to photovoltaic engineering (master's degree); from Mexico City to Berlin. Now, based in Rome, Guillermo's main scope of work is on reliability and performance engineering of utility-scale PV plants.

Constantinos Peonides is business development director for Alectris, with responsibility for expanding operations and leading all business development efforts globally. He is also the vice chair of SolarPower Europe's O&M and Asset Management Task Force and an active participant in the Digitalisation and Emerging Markets Task Forces. He holds a bachelor of engineering and an MBA from the University of Nottingham.

Will Hitchcock is founder and CEO of Above, a pioneer in the use of aerial inspections, digitalisation and data analytics within the utility-scale solar sector. With a bachelor's in engineering, he has extensive commercial, IT and engineering experience. During 2014-2015, as programme director at Push Energy, he constructed 150MW of ground-mounted solar. Will is a chartered environmentalist and in 2011 co-founded the UK's first community-owned solar co-operative, Green Energy Nayland.



Máté Heisz is the head of international cooperation at SolarPower Europe and coordinator of the body's Emerging Markets and Operations & Maintenance and Asset Management task forces. Prior to joining SolarPower Europe in February 2017, he spent four years in Tunisia working as a renewable energy advisor at the Tunisian Ministry of Energy on behalf of the German Development Cooperation (GIZ). Máté holds a master's degree in international relations from the Free University of Berlin and a master's degree in economics from the Corvinus University of Budapest.

Sampling guideline for inspection and testing of PV modules in the field

Module performance | Testing a sample of modules at an operational solar can help identify faults and underperformance in the wider plant, but which ones to choose? Authors from Mahindra Teqo describe a new methodology they have developed to Satish Pandey, Preetha Pillai, Sandeep Jadhav, Shyam Kumar, Gaurav Mishra, Rajesh Kumar Dhuriya

Solar photovoltaic (PV) system installations are increasing by leaps and bounds throughout the world. These systems are expected to produce clean, safe and reliable electricity over several decades of operation. However, PV installations are subjected to extreme environmental conditions that could result in deteriorating effects on the equipment's performance during their operational years. To ensure best performance and optimum ROI, these PV systems need periodic maintenance and testing throughout their operational phase. These practices can help to understand module degradation behaviour and provide essential information which can be used effectively to troubleshoot any problems arising within the system. Sampling for testing of PV modules comprises the procedures involved to select a part of PV modules from the entire solar PV plant for inspection and it should adhere to standard sampling methods IS2500/ISO-2859 and field-testing norms as per IEC 61215/61646 standards . The IS2500/ISO-2859 sampling plan has been designed mainly for the pre-dispatch module inspection at manufacturing facility. However, in field testing, the sampling needs to adopt the constraints of the field environment and limitation of the running plant. Accordingly, Mahindra TEQO has implemented the sampling plan with the stakeholders for whom the testing has been carried out.

Sampling selection criteria as per IS2500/ISO-2859

This sampling plan is a result of our expertise of handling a plus-3GW portfolio since 2012. The below mentioned sampling plan has been designed for electroluminescence (EL) testing, flash testing and visual inspection. Flash testing signifies the PV module maximum power output (P_{max}) at standard test conditions and helps to evaluate the comparative analysis with the rated power of the module. Flash testing is performed as per IS 14286/IEC 61215 and visual inspection of modules is performed as per IS14286:2015/IEC 61215:2016. Visual inspection can be done on a random basis and does not require any equipment for inspection. Hence it can be characterised as a general inspection. Similarly, a flash test and EL test are time consuming and costly, and thus cannot be done on many samples. In IS2500/ISO-2859 there are two categories – general inspection level and special inspection level. Based on our best practises we recommend General inspection Level-II for visual inspection and special inspection level S-4 for EL and flash testing, as given in Table 1. In the case of EL testing it interprets the existing micro-cracks, cracks and potential-induced degradation (PID) in the module, which affect the overall performance of the module. The IR thermographic inspection of PV modules is performed to detect non-conformities such as hotspot and diode failure. During thermographic inspection the evaluation will be performed on 100% of the plant modules or as per the respective requirement of the plant owner.

Sample selection methodology at PV plant

The sampling plan will apply to each module make respectively and the bottom-line approach is to not consider visually observed defective modules, which would give a false interpretation of average plant performance. If we have different module makes in the plant, then the sampling plan will apply as per the plant capacity but the total number of the samples will be distributed as per the weighted capacity of the modules at the plant. For example, consider a 10MW hypothetical plant with X make modules along with Y make modules and their

Sampling bracket	Plant size (MWp)	Number of modules in plant	Sample size for EL & flash test (as per special inspection level S4)	Sample size for visual inspection sampling (as per General Inspection Level II)
A	**Up to 0.0045MW**	2 – 15	2	2
B	**0.0045-0.008MW**	16 - 25	3	5
C	**0.0045-0.028MW**	26 - 90	5	13
D	**0.028-0.048MW**	91 – 150	8	20
E	**0.048-0.16MW**	151 - 500	13	50
F	**0.16-0.38MW**	501 – 1,200	20	80
G	**0.38-1MW**	1,201 to 3,200	32	125
G	**1-2MW**	3,201 to 10,000	32	200
H	**2-8MW**	10,001 to 35,000	50	315
J	**8-35MW**	35,001 to 150,000	80	500
J	**35-120MW**	150,001 to 500,000	80	800
K	**>120MW**	500,001 & above	125	1,250

Table 1. Sampling plan for field testing in solar PV plant as per IS2500/ISO 28591-1

Sample selected as per sampling plan					
Plant Capacity	**Samples selected**	**Module make**	**Proportion of modules in plant**	**Bracket**	**Make-wise number of modules selected**
10MWp	**32**	X	40%	E	13/32
		Y	60%	F	19/32

Table 2. Sample selection at PV plant with different module make

Plant Capacity	Number of modules	Sample size as per Table 1	Acceptable	Outlier
1MW	3,200	32	2	3

Table 3. Example for AQL

proportion in the plant is 40:60. Then, as per the sampling standard, the total number of modules to be selected for EL/flash testing will be 32 but these will be divided as per the weighted capacity of the manufacturer; thus, we must select 13 modules from X and 19 modules from Y.

To select modules from the plant Mahindra Teqo recommends following methodology:

1. If the PV plant is operational then the module selection should be made as per the inverter performance.
2. If the plant is not operational then the sample should be selected from a random pallet or module mounting structure/table.

For operational plants, the weighted numbers of each module make should be divided into least performing, average performing and maximum performing inverter.

- The selection of these inverters will be performed on a random basis with a stipulation of maximum three locations for each module make.
- After selection of the inverter, the next stage is to select the modules from the mounting table, which should be picked from the positive and negative end equally, and from the middle of the table. This helps to detect PID problems more accurately if they exist.

IEC standards 61215 and 61646 set out special testing requirements for crystalline silicon and thin-film modules respectively. Performance of a module at a site can be determined with the help of these standards. The flash test results should be interpreted as per the expected/guaranteed performance of the module make from the respective manufacturer/supplier. Also, if the corresponding results are not aligned with the expected performance values then a plant developer can reach to the PV module supplier/manufacturer as PV modules accounts for the 60% capex of the plant assets. This practice should be performed in accordance with the warranty agreements of the supplier/manufacturer.

Acceptance quality limit to be followed in compliance with ISO-2859

Acceptance quality limit (AQL) is an assessment criterion as per ISO-2589 in pre-dispatch statistical sampling plans. The notion behind including AQL in PV module assessment criteria is to bring it into alignment with the standard guidelines of ISO-2859. In field testing Mahindra Teqo has absorbed the AQL criterion primarily to validate the outlier selection during the assessment process. The outlier selection should be made through following the AQL 2.5 guidelines for major non-conformity as per ISO-2859. The AQL and the sample size code letter shall be used to obtain the sampling plan from Tables 1, 2, 3 or 4 (ISO-2589-1) attached at the end of the document. For a specified AQL and a given capacity of plant, the same combination of AQL and sample size code letter shall be used to obtain the sampling plan from the table for normal, tightened and reduced inspection.

As per AQL 2.5 of ISO-2589 two major conformities will be allowed for each module in acceptable range and if it is more than two it will be considered an outlier. Therefore, it will be removed from average calculation. The AQL process will be followed by the sampling process as proposed by Mahindra Teqo. For example, as given in Table 3.

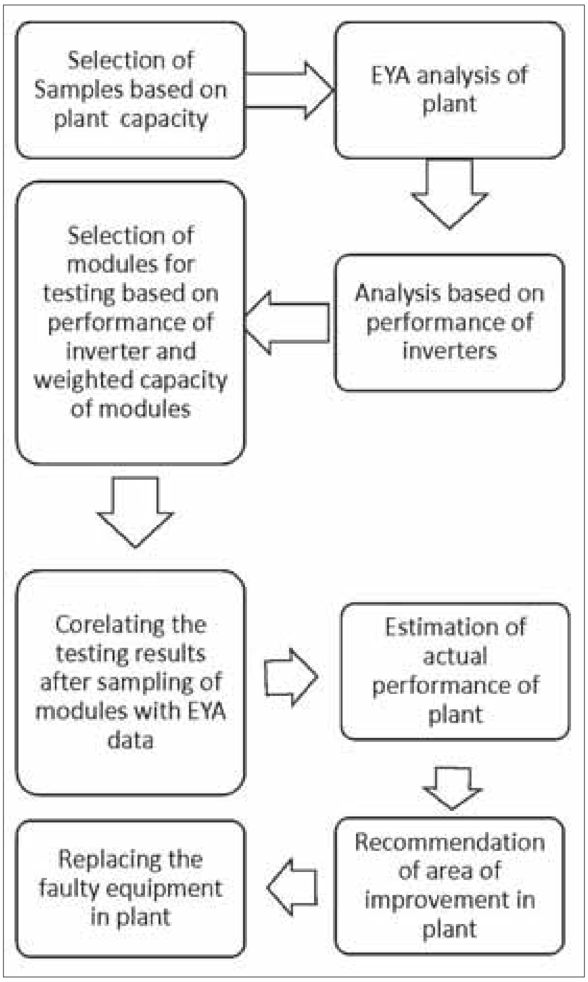


Figure 1. Sample selection to correlate EYA and field test data

Correlating energy yield data with field data

Mahindra Teqo has correlated the energy yield assessment (EYA) and samples tested on a PV plant to get the overall performance of the plant. This correlation is representative of the entire plant which is validating the sampling of modules.

Data from tested modules using this sampling methodology has been validated with the degradation obtained from the performance ratio (PR). A few examples of plants are shown in Figure 2. Plant A with 1.2MWp capacity was first analysed using daily generation data, where the module degradation based on the PR value is calculated. Then based on the plant capacity and performance of the inverter and watt peak rating of the module, flash testing is performed on modules. Based on the plant capacity the number of samples is selected as given in Table 1. It has been observed that in Plant A the degradation of modules obtained from flash testing is essentially the same as the yearly degradation obtained from PR, hence the sample selected for testing is representative of plant performance.

The PR calculation has the added uncertainty of other equipment such as inverters, cables etc., so calculation of the module degradation in the plant

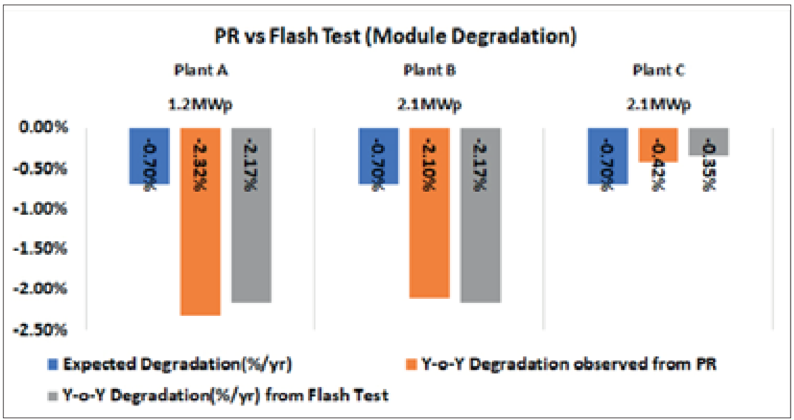


Figure 2. Module degradation obtained from PR versus tested module samples

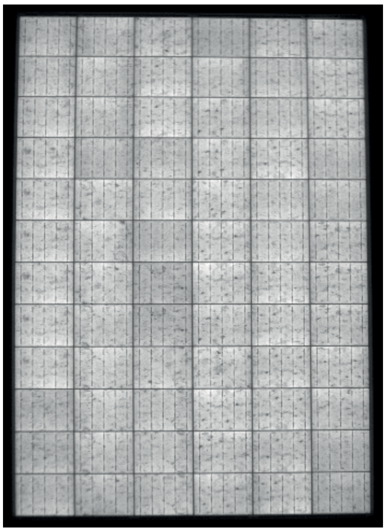


Figure 3. EL image of healthy module

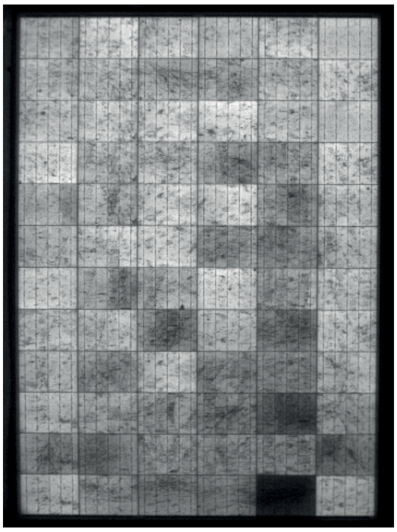


Figure 4. EL image with crack on module

is done by flash test, visual inspection, thermography and EL test of modules. This methodology is validated in the course of seven years of Mahindra Teqo's experience in the solar industry. Figures 3 & 4 show the EL testing of solar modules done on site, where the healthiness of solar module is checked. The samples for testing are selected as per the sampling guidelines recommend in this paper. Testing of sampled modules enables us to identify faults in the plant, apply corrective action and increase generation. If a 1MWp plant generates 1.70 million kWh/yr, then 1.5% extra module degradation can cause a loss in generation of 25,500kWh/yr. Based on a tariff of US$0.07/kW, this would result in a revenue loss of US$1,785/yr. Hence for a 100MW plant, which is quite common nowadays, the revenue loss will be 178,500 USD/yr – a significant amount. Therefore, identifying faulty modules through testing of selected samples can save revenue loss.

Conclusions

This sampling methodology can be used to ascertain the overall performance of a plant by testing sampled modules that represent the entire plant. There is no concrete guideline in a single standard available for field testing of PV modules in the market; to our knowledge, we are the first to standardise the whole process, and have prepared these guidelines based on our consultation with key stakeholders such as independent engineers, lenders, financial institutions, developers, EPC, manufacturer etc. This methodology is aligned with IS 2500/ISO 2859 sampling standards, which are defined primarily for pre-dispatch module testing; here IS standards have been incorporated as per field constraints. These guidelines will bring a coherency to field testing for PV modules, helping to standardise the process and will provide a common platform for every stakeholder to compare the results.

Authors

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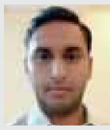

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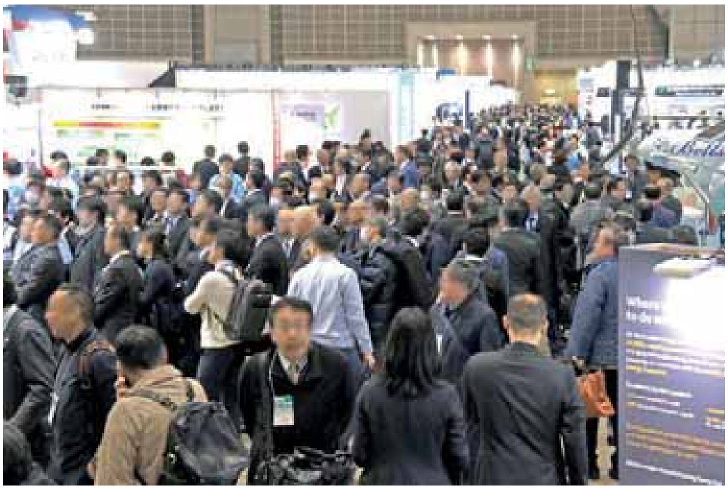
Testing a meaningful sample of modules from a PV power plant can prevent potentially large financial losses

Exhibit/Visit at Japan's Largest PV Show



Japan's largest PV show - PV EXPO, organised by Reed Exhibitions Japan Ltd., will be held from February 26 (Wed) - 28 (Fri), 2020 at Tokyo Big Sight, Japan under World Smart Energy Week – world's largest-scale smart energy show.

PV EXPO 2020 is expected to gather 70,000 visitors and 310 exhibitors including 70 newcomers! There will be 1,520 exhibitors in total of the 7 concurrent shows from all over the world.

In 2019, the show has concluded on a very high note with 66,576 visitors for 3 days (including concurrent shows) and was filled with active on-site business talks. PV EXPO has been attracting the huge attention from a wide variety of energy industries from around the world, and positive comments from exhibitors and visitors were heard everywhere in the whole exhibition halls.

The exhibiting space of **"PV EXPO 2020"** is nearly sold out and only a few spaces are available. Check the available booth locations and contact us immediately to secure your exhibit space in time and expand your business in Japan & Asia-Pacific!

Current Available Exhibit Space (As of Nov. 28th)
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*Spaces colored in white are available.

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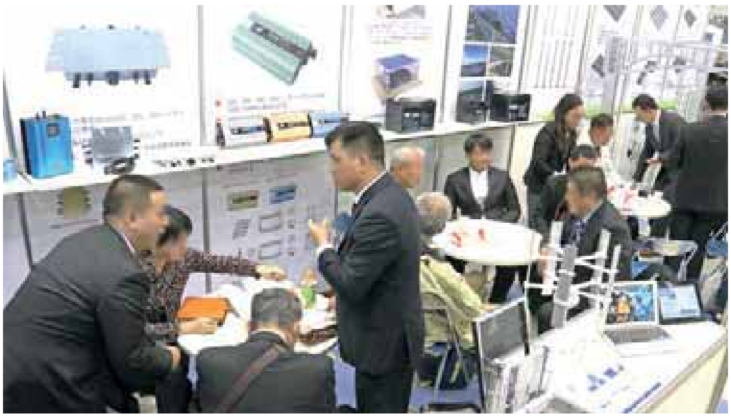

Floating solar sets sail for common ground

Innovation | A new World Bank-SERIS floating solar handbook has sparked a debate around whether standardisation could speed the segment's voyage to mainstream success. A-listers welcome the guide but insist too strict a focus on streamlined design could hamper innovation. José Rojo Martin reports

Credit: Kyocera

A new handbook has been published to help standardise floating solar design and construction

Of all the stories global solar has produced in its soon-to-end 2019 of dizzying growth, the coming of age of floating PV surely deserves to hold a special spot.

Having passed the 1GW installed capacity mark in 2018, the budding segment went on to dazzle in 2019 by squeezing project milestones in Singapore (50MW), Vietnam (49MW), Thailand (45MW), South Korea (25MW), the Netherlands (23MWp), France (17MWp) and many others in just 10 months. Of those put forward, a single venture – South Korea's 2.1GW Saemangeum – could alone take the industry to heights few would have predicted a few years back.

To the list of good news, add the fact that floating solar now boasts its very own how-to. The work of the World Bank and the Solar Energy Research Institute of Singapore (SERIS), the "Floating Solar Handbook for Practitioners" released in October 2019 is meant to offer a basic framework for developers to assess how a multitude of factors – plant design, energy yields, financial risks, green impacts – can hasten or hinder a project's journey from blueprint sketch to operational launch.

The bid to lay common ground is praised by all floating PV specialists *PV Tech Power* speaks to. All have witnessed the segment's unsteady shift towards far larger, more complex ventures. As the handbook notes, what floating PV wins in avoided land conflicts it loses with the rigours – corrosion, motion stress, natural hazards – that come with its harsher territory. Players coming into floating PV from other industries appreciate the guide's attempt to ease the way via the streamlining of processes.

"Standardisation is very important for any technology, something we've been pushing for with other sectors we're active in," says Lars Brandt, CEO of Sweden-headquartered mooring specialist Seaflex. The firm his father Bertil founded in 1960 has, he explains, spent years advocating for a more streamlined installation process in the marina mooring sector and others. He believes the philosophy is transferrable to the floating segment, which Seaflex started servicing around seven years ago.

According to Brandt, the firm has witnessed the evolution between its 112kW maiden floating PV mooring contract with New Jersey's Canoe Brook Solar in 2011 – "No one spoke about specific floats back then, it was all built on traditional pontoons," Brandt recalls – and its later work, including 1MW and 2MW ventures in South Korea. "The talk now is of megawatt, hundred megawatt sizes," he remarks. "The industry is taking really big steps forward … with completely new companies entering the field."

As it balloons in size, the floating solar industry must try and negotiate a better interaction with the relentless forces that surround it, Brandt believes. By way of example, he points at FRESHER, an EU-funded R&D programme run by Swedish, Spanish and Portuguese centres seeking to bring down installation costs by innovating around anchoring design. "It's all about optimising that interplay," the Seaflex CEO says. "In order to be bankable, floating installations must be certifiable."

Standardisation, both lifeline and corset

The scale of the plant design and operation challenge has not escaped those surveying the floating PV industry at the World Bank and SERIS. Among the segment's top current obstacles is, their joint handbook warns, the "technical complexity of designing, building, and operating on and in water (especially electrical safety, anchoring and mooring issues, and operation and maintenance)." Cable routing and management is "more critical" than is the case for ground-mounted PV, the guide says.

The widespread gratitude towards the World Bank-SERIS work does not stop some from warning against too heavy a focus on standardisation, particularly with

The floating solar industry is looking to Seaflex for our mooring expertise.

Seaflex is partnering with the floating PV industry to provide anchoring for their investments. After inventing the worlds first flexible mooring solution in the early 80s, Seaflex has continued to lead the innovation of anchoring methods for the worlds floating applications.

Seaflex has worldwide experience mooring anything from commercial marinas in hurricane prone areas, to floating hotel rooms and beyond. Since achieving longevity while taking environmental responsibility have always been cornerstones in the creation and development of the Seaflex mooring system, we are thrilled to provide our expertise as the PV industry makes the transition on to the water.

GEUMJEON, KOREA

Can Seaflex handle X,Y & Z?

Seaflex has experience handling extreme depths, vast water level variations and typhoon strength winds and surge. With minimal environmental data we can custom design a system that holds your application in place through your worst anticipated forces.

What is Seaflex?

Seaflex is a flexible mooring system that expands and retracts with the water level changes and waves, taking on and dampening the forces day after day, year after year. The system is custom made and produced in Sweden from high quality marine grade materials. We do not produce the actual pontoons or PV equipment, we design and supply the mooring system that keeps the floating investment in place.

Credit: Ocean Sun

Proponents of unconventional designs such as Ocean Sun's waterlily-like membranes are calling for standardisation not to go too far

design. Børge Bjørneklett, CEO of floating PV specialist Ocean Sun, appreciates the handbook's bid to streamline processes around site choices, funding and other areas but appears more sceptical when quizzed over the search for common ground around installation design.

"I see [the handbook] as a very useful document and I think SERIS have done a great job promoting floating solar," Bjørneklett tells *PV Tech Power*. "However, I'm slightly afraid of the talk of standardisation around the floats themselves." Noting that the handbook barely mentions the membrane design that is Ocean Sun's trademark – the approach is only discussed once in the 155-page document – he shares concern for the ongoing work to develop IEC standards for floats.

"It will make it even harder for us to market our technology, which I genuinely believe is a lot better than existing designs," the CEO says, pitching Ocean Sun's waterlily-like designs – installed across Norway, Singapore, the Philippines and soon in Albania – as cheaper thanks to lower polymer use and better-performing thanks to increased cooling. "It is difficult for small firms to enter the market right now," Bjørneklett says. "We don't have the home markets the bigger players started with."

One of such "bigger players" strikes a similarly cautious tone when asked whether design standardisation is friend or foe for floating solar. "SERIS are doing a great job and we thank them for their work. Any emerging industry like this needs quality standards to avoid negative developments that would hurt confidence in the systems," says Bernard Prouvost, chair of floating PV household name Ciel et Terre. "Standardisation cannot be, however, a brake for success and innovation."

Ciel et Terre – which styles itself as the "creator" of floating PV – claims to have installed 230MWp-plus worth of its Hydrelio HDPE [High-density polyethylene] platforms worldwide. As project sizes increase, so does the need for flexibility, Prouvost believes. "We must ensure that too much standardisation does not work against the innovation that is necessary to supply the market in big quantities and keep costs down," he says. "The technology should not be fixed too early."

Be water, my friend

As it leaves port and sails the choppy currents to mass-scale success, floating solar is being advised from many fronts to seek alliances with a sector that has called water bodies home for decades. That partnerships with hydropower hold great potential is a premise that runs front and centre in the World Bank-SERIS handbook. "Combining the dispatch of solar and hydropower could smooth the variability of the solar output while making better use of existing transmission assets – a benefit that could be particularly valuable in countries where grids are weak," the document enthuses.

The talk of synergies comes as no surprise to floating specialists. "The stress the handbook puts on floating solar's growth being linked to hydro dams is

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really important. It's something we've been advocating for a long while," says Ciel et Terre's Prouvost, pointing at the firm's own hydro-side ventures in Brazil and Portugal. "The synergies are really evident and can bring lots of advantages to dam owners too. It's a great possible future, perhaps the most important future, for floating solar."

As Ocean Sun's Bjørneklett puts it, hydro alliances are the "easier" way in for smaller floating PV specialists. "[Hydro dam players] are often very solid institutions, with typically good access to finance and also their own engineers, which means they can do due diligence on the technology," the CEO says. "Because they very often have good control of the reservoirs, they tend to have great relations with local governments, grid operators and others. They are currently our priority."

As it happens, floating solar-hydropower partnerships are too being explored from the hydro side of the divide. Multiconsult's Bente Brunes told a dedicated Intersolar Europe session, attended by *PV Tech Power* this year, of her firm's work to explore a 25MW floating PV add-on to a hydropower plant a consortium had rescued from ruin in Liberia. Interviewed by this publication in November, Brunes elaborates on why she feels this is an avenue worth contemplating for either side.

"These alliances should be an interesting option for hydro players to look into, but also solar developers," says project manager Brunes, herself an engineer with over a decade of work in the hydro sector. "With solar plants getting bigger, and the intermittency that comes with that, the synergies are very beneficial in terms of frequency regulation for countries facing challenges around shortages. They can use the reservoir very actively to store water during the day and use it at peak hours of the evening."

Brunes does see obstacles in the smooth merger of floating PV with hydro dams, not least whether mooring systems are built to withstand the constant fluctuation in water levels. For his part, Ciel et Terre's Prouvost points at technical issues in certain environments – adapting to harsh shadows in deep, V-shaped valley dams such as Switzerland's can add to costs, the chairman says – and the regulatory headaches created by the fact that the dam owner is not always the water body owner.

Technology, Prouvost adds, could be key in maximising the synergies. "Adding smart systems and artificial intelligence can help the dam owner decide when to use solar and when to use the water to ensure the market receives the right amount of energy at the right time and at the best price," the chairman points out. "There is some progress yet to be made around firms being able to build intelligence into the system."

The green conundrum

Another side-effect of floating PV's new-territory status is that developers remain, to some extent, in the dark about how their projects will impact ecosystems in the long term. As the World Bank-SERIS handbook puts it: "Because [floating PV] is a relatively new industry, additional studies, adaptive management, and long-term monitoring will be required to assess and understand the effects on water quality and aquatic flora and fauna."

Noting that long-term impacts on water quality are not established, the guide advocates for a "precautionary approach" over the next few years. This, the handbook explains, may entail setting "initial limits" on how much water surface is covered and avoiding developments in the high-biodiversity coastal strips nearest to shore. Some of the floating solar operators approached for this feature feel the philosophy is too restrictive, even if all regard green impact monitoring as key.

"I'm not so sure," confides Ciel et Terre's Prouvost. "Of course there should be consultation with local authorities and communities but we shouldn't say now, without testing it, that near-shore floating plants are bad for ecosystems." He points at studies by Ciel et Terre alongside Taiwanese universities which found, he says, that floating PV is compatible with fish farming. "It's obviously key that standards are put in place on pollution, biodiversity but let's not be too conservative," he adds.

Ocean Sun's Bjørneklett agrees, meanwhile, that minimising green impacts is a "sound principle" but argues that smaller systems pose little concern, particularly in artificial lakes. According to him, the firm has worked to certify its polymer structures in the Philippines projects to ensure they do not harm local biology. "When installations start covering a certain percentage, however, I do think a marine biologist should be brought along to survey the environmental impacts," the CEO remarks.

Quizzed over the merits of the handbook's precautionary approach rationale, Multiconsult's Brunes appears similarly ambivalent. "I think in general it's good to be cautious and assess how a floating PV addition impacts the dam, the surrounding agriculture that's existed for decades," she says. "But I'm not sure about the idea that if we don't have data then we cannot do it. It's of course important to learn from past experience but at one point you're going to have to start from somewhere."

Brunes does welcome the handbook's focus on environmental risks, and advises firms to address questions including whether the floating plant stops sunlight from reaching the bottom of a water body, its impacts on endangered or migratory species and on the access of local communities. She agrees that data remains deficient and says the gap could be plugged via a collaborative approach: "If developers start monitoring, logging data to then share it globally it would be very beneficial. The unanswered questions are many and the way to get answers is to start with the research."

Show me the money

While all interviewees do see the value of hydropower co-location and sound environmental management, the sentiment is that for floating PV, true tailwinds can only come from a much talked-about acronym. That levelised cost of electricity (LCOE) will be the top enabler of the segment's commercial success was apparent at this year's Intersolar Europe session, with developers repeatedly asked by a critical audience to produce hard figures for project costs and returns

For smaller proponents of unconventional designs, the difficulty can lie in proving that different can also mean bankable. "The challenge for us has been to properly validate and document our systems in the eyes of clients and investors," says Ocean Sun's Bjørneklett, who explains the firm has engaged or plans to engage third-party players to help certify its trademark membranes. "Clients, however, or at least those who work with us, have spent years looking at the different floating PV designs and identified ours as the most favourable," he adds.

The stronger foothold of more established names does not save them from challenges either, though. Ciel et Terre's Prouvost notes the influx of rivals in recent years – sparking disputes around patents he says are always "difficult to defend" – and the headaches created by the rise of larger projects, driven by developers' need to ensure profitability is not dented by lower electricity costs. "We're now working on projects of 100MW and even upwards of that," the chair says. "It's a change in the system, and manufacturing must be able to provide the market with enough quantities."

Whether new or old, all floating PV specialists currently face the same adverse market dynamic. Ciel et Terre's Prouvost points at the shift from feed-in tariffs to competitive tenders underway across much of global solar, which forces floating players to compete against ground-mount PV, wind and other entrenched technologies. "We see capex differences of 10% with ground-mounted. It's not that huge but it can make a difference in winning a tender," Prouvost says. "Through R&D we are lowering our manufacturing costs but not as quickly as solar panel prices are decreasing."

For her part, Multiconsult's Brunes warns that regulatory, planning and technical requirements will mount as project sizes increase, potentially dilating the already lengthy timetables floating PV faces to hit financial close. She believes the segment's inherently more complex designs could mean it will always be pricier than ground-mount PV but adds that floating PV's side benefits could tempt investors, particularly when the novelty factor wears off and understanding improves.

The recently completed 14.5MWp Sekdoorn plant in the Netherlands was designed to optimise the levelised cost of electricity, according to developer Baywa r.e.

Others may not put that much stock in standardisation but to Brunes, the potential is clear. "Of course, it's important not to limit competitiveness as that is key for floating PV to build up. If this is about achieving identical solutions, innovation would be damaged," the project manager says. "The way I think about standardisation is adopting a set of rules to define the forces plants must be able to withstand, how to calculate energy yields and so forth. Setting expectations for the quality projects must achieve, rather than how they must be designed or shaped, would be very beneficial."

Whatever the speed of travel, whether standardisation will bring headwinds or tailwinds, those placing bets on floating solar do not doubt it is destined to travel far. The handbook's "conservative" estimates of a 400GWp technical potential augur the segment a golden future. Optimists include Ocean Sun's Bjørneklett – he expects the industry to hit grid parity "very soon" – and Ciel et Terre's Prouvost, who believes the line has already been passed in countries such as Japan. Seaflex's Brandt mirrors the bright outlook. "Already now we're keeping pace with ground-mounted solar and in a couple of years, we'll be below," he predicts. ■

"Floating Solar Handbook for Practitioners" is available to download at http://documents.worldbank.org/curated/en/418961572293438109/pdf/Where-Sun-Meets-Water-Floating-Solar-Handbook-for-Practitioners.pdf

Getting tough on solar soft costs

Project economics | Alumni from SunPower's recently wound up project business are spearheading a new venture targeting large-scale solar's soft cost problem. Ben Willis hears how they plan to harness the power of digital technology in tackling one of the industry's persistent pain points

Credit: Terabase

Matt Campbell, third from left, and Chris Baker, second from right, are two of the former SunPower staffers taking on solar's soft cost problem through Terabase

In the quest to continue driving down the levelised cost of solar energy, all facets of a PV power plant are fair game for potential savings. In recent years, the solar industry has been extraordinarily successful in targeting system hardware to bring overall project costs down; module prices have plummeted drastically and increasingly affordable innovations in inverter and tracker technology have given developers powerful new tools to wring ever more value from their projects.

But one area that is "overdue for disruption" is that of soft costs, says Matt Campbell, co-founder and CEO of Terabase, a new Silicon Valley-based venture recently launched with exactly this aim in mind.

According to Campbell, while falling costs in hardware have helped reduce the average price of large-scale PV systems by up to 88% in the past 10 years, soft costs have failed to follow a similar trajectory. The result is that these costs, defined as the non-hardware portion of a project's costs – development, EPC management, labour, logistics – are now proportionally more significant in a system's overall economics.

"There just hasn't been enough innovation applied to it yet," Campbell says. "Hardware has seen tons of innovation. Inverters today are 5MW, 1,500V; when I started doing projects they were 100kW and 400V. It's the same thing with panels, the same things with racking. So there have been huge amounts of innovation, lots of investment. But we haven't seen the same in soft costs. The way we build projects today isn't that much different than the way they were built 10 or 15 years ago, even though the projects themselves have changed dramatically."

Industry followers may recognise Campbell's name from the many years he spent in the upper echelons of US manufacturer and erstwhile mega-project developer SunPower. During his time at SunPower, Campbell was involved in many of the company's ground-breaking ventures, but will probably be best known as the architect of the Oasis platform, an integrated power plant solution designed to streamline the construction and operation of utility-scale PV projects. Oasis and comparable modular approaches to PV power plant design and integration devised by other companies have been instrumental in helping drive down the costs of large projects over the past 10 years.

Campbell is aiming to bring similarly innovative thinking to his latest venture. Earlier this year SunPower announced it was quitting the large-scale solar development business to focus on distributed generation. The emergence of Terabase is a direct consequence of that strategic move, with SunPower alumni accounting for six of the new company's core team.

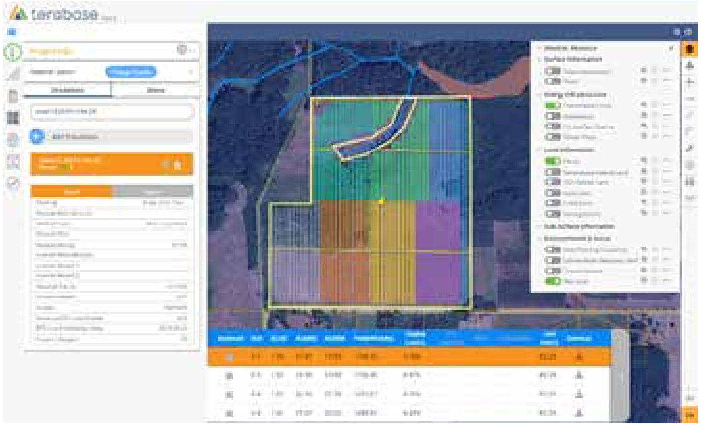
Despite the many directions a company boasting such personnel could have taken, Campbell says a decision was taken early on to adopt a narrow focus: "When we started the venture, we really looked at the market and considered different business models, including project development. And we certainly come from that background. Our conclusion was that the project development market is well served – there are a lot of small and big players globally in a very competitive space, so we felt that our best way to add value was not to be a project developer.

"However, we saw that we could leverage our experience of project development to go after soft cost. The thesis is this: hardware has gotten cheap; panels, inverters and racking systems have seen spectacular cost reductions over the past 10-15 years. But soft costs have been stubborn and as a percentage of the overall project value have become more substantial. So when panels were US$2-3 per watt, 25 cents of soft costs was less important. But now it can constitute about half the cost of a project."

The power of digital

Terabase hopes to succeed where the industry has so far perhaps not failed altogether, but certainly failed to act in a concerted fashion, by offering developers a powerful tool to begin driving out some of those persistent soft costs. Its central offering is a digital platform designed to accelerate and simplify the early stages of developing a project, which can involve a labour-intensive and costly set of processes. By merging a wide range of datasets, the Terabase platform is intended to enable a developer to undertake in a few simple, desk-based steps what might otherwise take months or years.

"[The platform] focuses on the decision-making processes from the very beginning, where you're doing greenfield siting and trying to find an optimal site, right through to design optimisation, where you've got a piece of land, you've got a project footprint and you're trying to finalise your technology choice to optimise the value of your PPA and minimise your LCOE," explains Chris



Credit: Terabase

Baker, another Terabase co-founder and now the company's executive vice president of sales and marketing. "And that's a one- to three-year cycle probably on a project before you go into detailed engineering."

To enable such streamlining, Baker says, the Terabase platform incorporates publicly available GIS data with a number of proprietary layers to enable users to gain a quick understanding of a prospective site's key attributes and constraints – things such as topography, weather data, transmission access, underlying real estate and so on. It also features a number of pre-set kits that enable a non-technical user to simulate and compare the performance of different technologies – PERC, bifacial, half-cell, trackers, fixed-tilt – on their prospective sites.

"The old school way of doing this is site surveys and physically going out to capture that information," Baker continues. "Now, you still need to do that to build the project, in almost every case, because you've got to field-verify what you're seeing with publicly available data. But the big benefit is that you are deferring the need for some of these field surveys by doing a pre-check using digitally available layers. And you're spotting obvious risks and constraints so you know what to go and look for."

"The way to think about it is it's half a GIS tool and half a solar project engineering tool," adds Campbell. "There's different software that's available in the market, especially in the DG space, but we built our platform exclusively focused on the utility space, which has a much different set of requirements. And we thought this integration of GIS with project engineering is important. The other thing is we really target a non-technical user, because normally you've got a developer working in partnership with a technical team; we wanted to empower the developer to do a lot of the early technical economic assessment quickly, using software but without the need to go through a lot of detailed engineering."

Added value

The data held within the Terabase platform is of course largely available already on various digital platforms, but bringing it all together in one system generates certain efficiencies to the user who no longer has to toggle back and forth between several different systems, says Baker. "But the big benefit is really more to be able to defer engineering spend earlier in a project's life. You can cast aside bad projects quicker, you don't spend time or money on them and pick better sites right from the get-go," he adds.

Campbell says there are plans to improve the breadth and depth of data held on the system and also to add new functions, such as one that will automatically generate estimates of a project's likely EPC cost and internal rate of return. "Those two components are important because we want to help the developer find which configuration has the best economics. So this will provide a quick answer to that question," he explains. Further planned functions include the ability to generate a bill of materials, a schedule and optimised logistics plan. "So this is just the first step in a long journey of digitalisation," adds Campbell.

The basic Terabase platform is currently offered free over the internet. The company operates a premium business model, in which it then offers clients products and services on top of the basic platform. "For example, if you want half-metre resolution on satellite data, we can sell that data to you through the platform," says Campbell. "We can commission drone flights, we can do detailed CAD engineering in our engineering back office we've set up – there are a bunch of paid services we can offer. But we think there's a lot of value in the basic functionality being free, because it's a great tool for developers and we want as many people to use it as possible."

Campbell is hopeful that the Terabase platform and the company's additional services will make a meaningful contribution to reducing the hitherto persistently high soft costs of large solar projects. "Obviously it's project dependent, size dependent and country dependent," he says. "But I would generically say that for an average 100MW project the target for us in terms of value creation is 7 cents a watt, which depending on the location could be about 10% of the project value. And that's a combination of building projects less expensively and building them faster."

Terabase's platform offers a variety of digital tools to speed up the early stages of project development and design

"A juggernaut of solar"

Looking at the bigger picture, Campbell believes that the wider digitalisation of solar, of which the Terabase platform is just one part, is a necessary process the industry must go through if it is to capitalise on the huge opportunities that lie ahead. His view is that in spite of the industry's many successes to date, in terms of large-scale power plants, "less than 1% of what will eventually get built has been built". "It's just going to explode in the coming years," Campbell says.

A game changer for Campbell is the likely adoption of bulk storage, which he predicts will come of age in around five years' time, leading to a significant uptick in the scale of solar projects being built. "That will just unleash a juggernaut of solar, because if you have cost-effective bulk storage, you'll do projects that are four or five times bigger," Campbell says.

When that happens, the industry will have little choice but to be a whole lot smarter about the way it builds projects, and his hope is that Terabase will be at the forefront of this process. "That's the philosophy of our company; our name is reflective of that – 'Tera' is for terawatt and 'base' is for baseload energy. And the hypothesis is, if you're going to terawatt-scale baseload solar, how would you do it? And the conclusion is, it's got to be completely digital. That's not tomorrow, next year, but over the next five to 10 years."

Bringing retired PV modules back to life: From science-fiction to the reality of the circular economy in the PV sector

Module waste | The growing volume of PV waste presents an emerging environmental challenge, but also brings substantial value creation opportunities as the idea of bringing decommissioned PV modules back to life becomes more feasible. Researchers from imec, VITO and SoliTek chart the development of the second-life PV business as it transitions from theory to practice

Volume growth brings waste challenge

The solar photovoltaic (PV) energy industry is experiencing a radical growth, particularly evident over the last decade, evolving from a niche market into a large-scale, mainstream, cost-competitive renewable energy technology. The fact that nearly 80% of the worldwide PV installations (and, thus, PV modules) have been deployed only during the last five years speaks for itself. With the installed PV capacity today exceeding 600GWp, and in view of the current annual growth rate of 25-30% for new PV installations, we are entering the dawn of the terawatt (TW) era of global PV installations, a milestone that is foreseen to be reached by 2022 [1].

On the shadow side of this success, the number of PV modules that reach the end of their useful first life will also greatly increase after the time lag of lifecycle operation, accumulating proportionately as PV waste. Indeed, this massive growth of PV installations is translated into global PV waste projections of up to 8 million metric tonnes by the end of 2030; and up to 60-78 million metric tonnes cumulative, by 2050 [2]. As such, the ratio of PV waste to cumulative installed PV volume, being today lower than 0.6%, is expected to exceed 80% by 2050. Further to consider, these projections account neither for PV waste at production level nor waste from decommissioned PV for economic reasons, i.e. insurance claims and repowering. In other words, PV waste volume could even be much higher.

In this context, the exponentially growing PV waste presents an emerging technical and environmental challenge. Rather than considering such challenge a mountain too high to climb, one can envisage unprecedented, multifold value creation opportunities, such as new financing mechanisms and multiple revenue streams, across the whole PV value chain. Besides, PV recycling, recovery of raw materials, repair or refurbishment of decommissioned, failed or degraded PV modules and their recommissioning (second-life PV modules), are indispensable for a more sustainable, environmentally friendly and economically viable solar energy-based future.

From linear to circular business in the PV sector

Up to recently, PV end-of-life (EoL) management approaches have been mostly examined from the perspective of conventional product-based single-path business models (Figure 1):

1. A supplier sells new PV modules and batteries to the end-user;
2. The user then manages the PV energy generation;
3. Real-field (operational) life of a PV modules reaches the end;
4. PV modules enter the waste stream and are either recycled or disposed.

Indeed, in most cases, by default, once PV modules are decommissioned or fail, they enter the waste stream and are either disposed as waste (in their majority) or – in the best case – recycled, with the latter option representing today a clear minority of <10%, compared to disposal. Recent advances in PV recycling technology and processes, as well as pilot projects, led by PV recycling pioneers, such as PV CYCLE, First Solar, SolarWorld, Loser Chemie and

Figure 1: Simplified illustration of the conventional product-based single-path business model for PV modules, throughout their market and operational lifetime

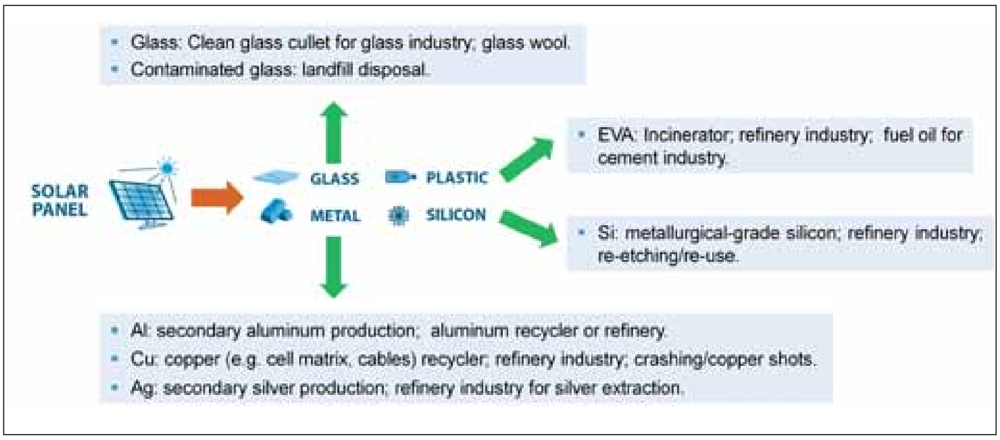


Figure 2. Recovery and secondary use streams for the different PV components and materials

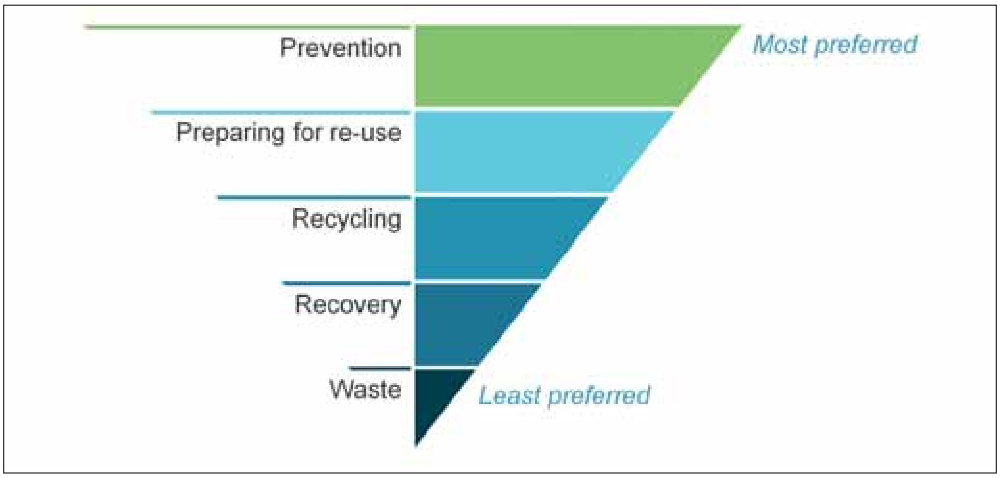


Figure 3. Waste hierarchy, also applicable to PV EoL management, according to the EU waste legislation

NPC Group, allow the recovery and re-use of most materials in a PV module (Figure 2).

The first complete system-scale PV decommissioning and high-value recycling, which was undertaken by a commercial service provider and resulted in the remanufacturing and recommissioning of second-life PV modules, has been reported by K. Wambach et al. [3]. The case study was led by SolarMaterial AG who, in one year, completed the recycling of Germany's oldest PV system, installed in 1983 on the Pellworm island. In total, 17,568 PV modules have been dismantled and recycled, the recovered solar-grade silicon wafers were reprocessed by Sunways AG and the new-made cells were used for manufacturing of new PV modules by Solarwatt. All PV modules, that were installed in this "second-life" PV system, were certified by SolarWorld AG as original equipment manufacturer (OEM) products, with full warranty (25 years).

Beyond recycling and recovery of raw materials, repairing/refurbishing PV modules for re-use (i.e. second life) or even preventing PV failures are even more preferred EoL practices, in view of the relevant legislation on waste hierarchy (Figure 3). Indeed, PV modules with extended lifetime (or second life), through their re-use or repair, will increase their overall (lifetime) energy yield, for the same bill of materials and embedded energy used for their manufacturing, eventually lowering their lifecycle environmental impact.

In quantitative terms, CIRCUSOL [4] and field PV reliability experts [5] reckon that 45-65% of failed and/or decommissioned PV modules today can be diverted from the disposal/recycling path, towards second-life PV (re-use), upon repair/refurbishment. In practice, this ratio is likely to be even higher since decommissioned though functional PV modules currently also enter the aforementioned waste stream.

It becomes clear that the aforementioned "take-make-dispose" linear models (Fig. 1) are neither sustainable nor sufficient to bring out the environmental, technical and economic benefits of PV recycling, repair/refurbishment and re-use. On the other hand, circular business models and cradle-to-cradle designs can be the key towards streamlining EoL decision-making which, in turn, can help to slow, close and narrow resource loops in the PV sector. On this basis, a *Product-Service System* (PSS) has been proposed by CIRCUSOL, to enable the implementation of circular business models in the PV sector (Fig. 4). Such a PSS-based circular business model:

- introduces *product service providers*, to consolidate and carry out decision making for the optimal life path for each PV module, as well as to co-create value propositions to the PV end-users;
- incentivises innovation towards PV designs-for-circularity (see section 'Designs-for-circularity'), that facilitate second-life paths, i.e. recycling, re-manufacturing or refurbishment and re-use.

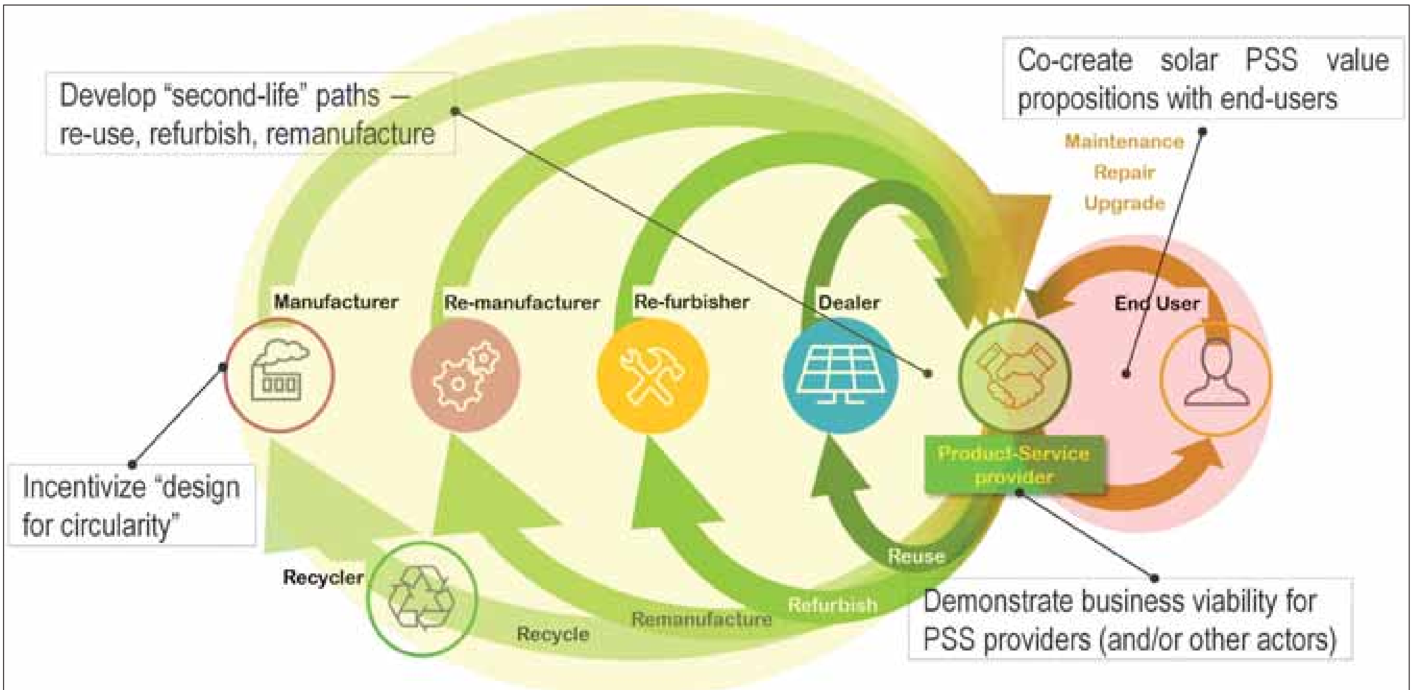


Figure 4. The PSS-based circular business model, envisaged in CIRCUSOL project; coupling circular product management and value-added product service

A	As good as new, only minor abrasion, marks, defects, etc.
B	Degraded anti-reflective coating; Encapsulant and/or backsheet discoloration, minor delamination in the middle cell areas; Snail trails with < 10% loss in module's power output.
C	Cracked cells with < 10% loss in module's power output.
D	Damaged junction boxes and/or cabling that should be replaced; Failed bypass diode(s) that can be replaced (non-potted junction boxes).
E	Backsheets with cracks or abrasion that could be repaired.
F	Modules affected by PID.
G	Unacceptable, non-repairable module damage: fractured glass, hot spots / burn marks, excessive delamination, broken cell interconnection or failed solders, corrosion, cracked cells and snail trails with > 10% loss in module's power output; modules with safety concern.

Table 1. Proposed classification of observed defects and failures of PV modules, to determine their repairability

Field experience and second-life PV business: State of play

In the course of PV modules' operational lifetime, physical degradation, defects or failures may occur in only a single component (e.g. cell cracks or bypass diode failures); whereas the rest of the module structure itself may remain intact. Different reliability issues at a PV module level can be classified into infant mortalities (<4 years of field exposure), mid-life failures (beyond four years and fewer than 15 years of field exposure) and end-life or wear-out mechanisms (>15 years of field exposure, until and beyond the module's performance warranty) [6]. Field experience indicates typical PV module failure rates ~0.15-0.25% per year, meaning that approximately 2% of the entire fleet of a PV plant is predicted to fail after 11-12 years [6].

The most commonly experienced reliability issues and failures of PV modules in the field are encapsulant delamination and browning; fractured glass, frame or backsheet; bypass diode and junction box failures; cell cracks (often with consequent snail trails); broken cell interconnections; corrosion and potential-induced degradation (PID) [5, 6]. The necessity and time (urgency) of decommissioning PV modules with such problems, and the decision for repair (if technically feasible) is largely based on on-site visual inspection and field characterisation, combined with empirical evidence. Table 1 proposes a classification of such failures observed in fielded PV modules, to determine their repairability. Field experience and current technology indicate that, in principle, repair/refurbishment of PV modules and/or recovery of their electrical performance may be typically applied to: i) defective frames and mounting clamps; ii) faulty bypass diodes and defective wire connectors in junction boxes; iii) certain PV backsheet defects; iv) early PID.

Eventually, as indicated in Table 1, some cases of PV module failures, such as damaged (fractured) glass, cracked cells and snail trails, turn out to be beyond refurbishment. Whether refurbishing a PV module is worth it or not often depends on the kind of failure and the layout of the PV system where the module was installed and operated during its first life. For instance, building-integrated PV (BIPV) systems may need to be completely dismounted, even if only few individual (repairable) modules fail, to ensure the integrity of their multifunctionality (e.g. waterproofness) [7].

Therefore, before any repair, each PV module is cleaned and undergoes electrical (I-V) characterisation, by means of a solar simulator, while any kind of defect or failure is thoroughly documented, through additional thermal/optical characterisation methods and visual inspection. Then, repairing certain defective parts of a module is, at most times, a straightforward task. For instance, defective junction boxes or bypass diodes are completely removed and replaced by new ones. Upon completion of all repair tasks, the refurbished (second-life) PV modules undergo a new I-V characterisation to determine their new power, current and voltage outputs. In terms of reliability/qualification testing, an IEC 61730-based high-voltage test is a common practice among repair service providers, to ensure safety. Finally, upon its qualification, each refurbished module is commissioned and accordingly packaged for shipment.

Recently, Glatthaar et al. [8] introduced "PV-Rec", a practical tailor-made repair/recycling process for individual PV modules based on a reliable failure analysis and selection procedure (Figure 5). In that approach, visual inspections of EoL or failed PV modules are complemented by electroluminescence (EL) and/or infrared (IR) imaging measurements [9] and I-V characterisation, similarly to the task flow described above. In this way, module defects/failures are accordingly quantified and classified, so that the most appropriate recycling or repair procedure can be assigned to each module. In the same study, refurbishment could ideally be achieved by eliminating module defects in single repairs, which fully restore PV modules' operational status.

Apart from individual cases of failed modules, repair/refurbishment can also be performed to entire strings of a defective installation. Specialised companies can produce small runs of refurbishable modules; however, repairs may only be viable starting at a certain number of modules, as this is done by small manufacturers and requires manual labour and experience. In general, the greater the number of faulty PV modules that can be repaired at once the better, because the responsible technician needs to remove each module and place it on a transport pallet.

Recently, upon maturation of the PV industry in several countries, pioneer companies and platforms emerged and are offering refurbished second-life PV modules. Notably pvXchange, SecondSol and Solar-Pur GmbH offer mostly for business-to-business (B2B) and exchange platforms, trading in decommissioned and refurbished PV modules and components [10-12]. Such platforms may also provide

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Denver, CO

Solar Power MEXICO
IN PARTNERSHIP WITH Deutsche Messe, SNEC PV POWER EXPO, SOLARPOWER INTERNATIONAL
March 24-26
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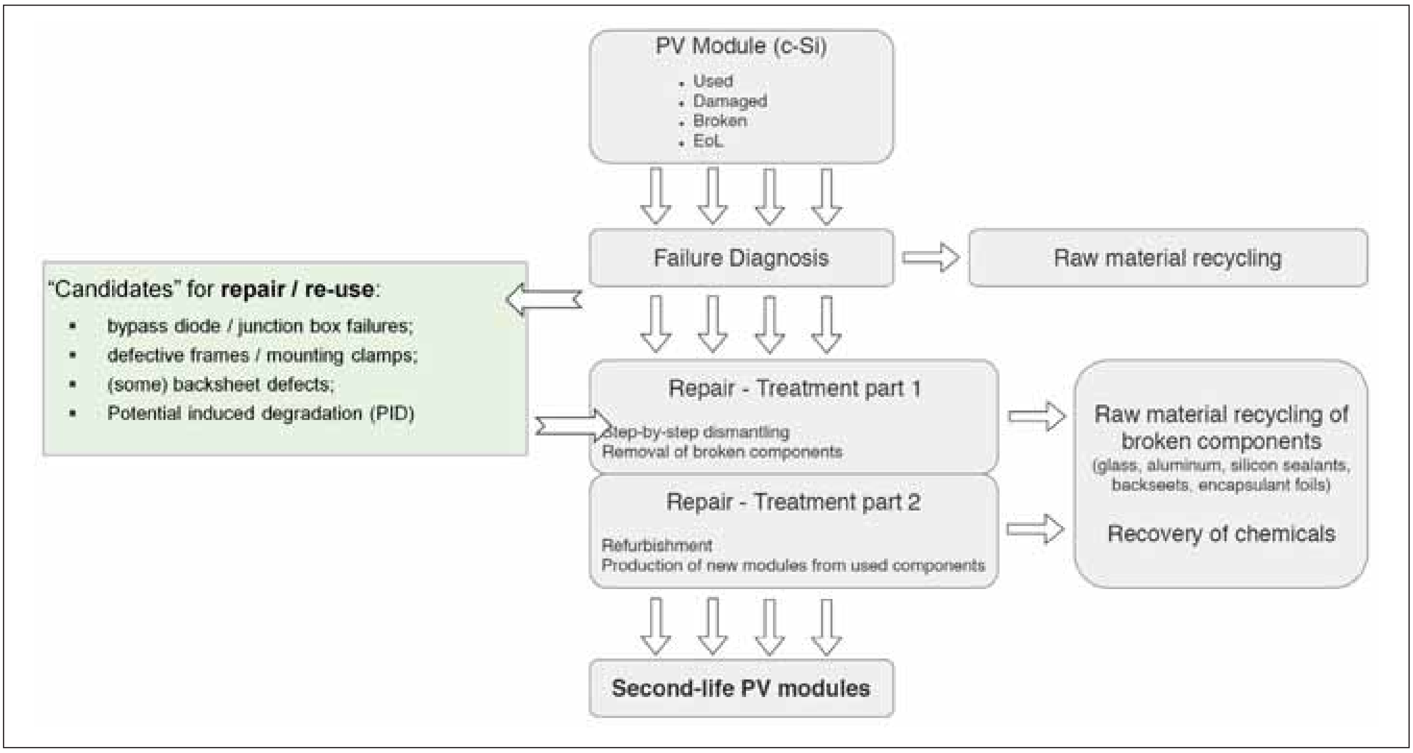

Figure 5. An adapted procedure towards second-life PV, based on the "PV-Rec" concept of J. Glatthaar et al. [8]

quality control, repair and installation services. PV modules' repair/refurbishment is commissioned by PV installation or insurance companies with positive experience in relevant repair projects, and the repaired PV modules are typically given a two-year warranty [7].

At the core of second-life PV module business, SecondSol's and Rinovasol Group's GmbH activities range from collection and repair of decommissioned or failed PV modules to the quality control/testing and trading of second-life (refurbished) ones [12, 13]. Rinovasol Group reckons that up to 90% of defective PV modules are potentially repairable, while claiming three international patents in relevant technology and design aspects, as well as IECEE CB Scheme certification [13]. Indicative repair/refurbishment costs for PV modules range from approximately €20 (US$22.16) to up to €90 per module, considerably depending on the handled volume, the quantity or severity and type of failure/defect, as well as on the required characterisation/testing, prior to and after repair [12]. It does become evident that second-life PV modules close to the upper margin of such repair-for-reuse costs, cannot even be competitive, cost-wise, with brand new (thus, of higher efficiency) PV modules that have the same (or even lower) price tag. One would then wonder if and how second-life PV and re-use business can survive today such fierce competition, in a market of consistently decreasing PV module prices. The recurring though plain explanation is that, in many cases, PV system owners and operators need to replace failed/decommissioned PV modules with identical or similar ones, in terms of type/model or (at least) power rating, to retain existing subsidies and feed-in tariffs. Therefore, apart from being a "greener" option, second-life PV module types provide a straightforward solution and prompt replacement for "retired" PV modules that are neither produced anymore nor traded as new today.

Looking at today's technical landscape on post-repair PV reliability testing and (re-)certification, second-life PV traders and relevant service providers face substantial challenges. Although the PV industry gained, through the years, significant experience in PV reliability issues, this experience is largely based on rigorous and extensive "design qualification" and "type approval" testing sequences for newly produced PV modules, i.e. under controlled laboratory conditions, as per IEC standards.

On the other hand, those familiar with the PV industry recognise that repair and/or refurbishment of second-life PV modules remain rather informal and certainly neither systemised nor standardised. In fact, these activities are independently performed by the aforementioned companies, with limited (or even without) support from the original PV module and component manufacturers. On this basis, today, there are only limited insights and hardly any standards on the characterisation, reliability testing, certification or labelling for second-life PV modules. Yet, it should be clarified that, from a functional perspective and in view of the Low Voltage Directive (LVD) (2014/35/EU), relevant conformity assessment and safety requirements are still applicable, equally for both first- and second-life PV modules.

In this rather vague context, details on the reliability/qualification testing of second-life PV modules that are adopted and applied by the aforementioned actors are not publicly disclosed. As a result, claimed duration of warranty periods for refurbished PV modules may be judgement-based, somewhat subjective and often misleading or misinterpreted. Besides, the extent and nature of the applied PV repair/refurbishment actions should be carefully drawn, to ensure the integrity and validity of CE (i.e. *Conformité Européenne*) marking in second-life PV modules to be traded within the European Union. However, most importantly, efforts towards re-certification and quality standardisation for such modules neither exist nor are practically under any development at this moment, as TÜV Rheinland and IEC experts reckon [14, 15].

How can second-life PV become reality in circular business?

Designs-for-circularity: Innovation and opportunities

Exemplary innovations and material/design-for-recyclability practices that (potentially) facilitate circularity are found on both material/component and module/device level. Apollon Solar's NICE technology, which can render PV modules encapsulant-free by replacing the encapsulant layers with neutral gas filling, simplifies the fabrication process (no soldering, no lamination needed), while enabling more environmentally friendly and simple PV recycling process, claiming 100% recyclability [16-18]. Also, the use of glued ribbons or electrically conductive adhesives, can eliminate the need for lead-based ribbons, thus allowing recycling/recovery processes free of hazardous lead waste residues [19-21]. Besides, considerable technical complications in PV recycling, associated with the challenging elimination of EVA or POE, can be overcome with the incorporation of alternative materials, such as silicone sheets [22].

From a more procedural and workflow perspective, the integration of radio-frequency identification (RFID) technology in PV modules can streamline collection-transportation-processing schemes, by tracking and identifying decommissioned PV materials and waste, on the basis of reverse logistics [23]. In turn, the latter comprises an excellent facilitating tool towards PSS-based circular business models for the PV industry.

In all cases, these innovative design solutions do not grasp yet any significant market share, due to their relatively high cost and/or their unproven field reliability and applicability.

4.2 Second-life PV: R&D gaps and key market factors

As of today, there are substantial gaps in knowledge/R&D and technology, in relation to the segments of PV refurbishment/repair and second-life PV reliability testing. This, in turn, explains the much smaller and relatively fragmented market being addressed, in contrast to the thriving standard PV business and the immense growth of PV installations. There are two main "pillars" of R&D gaps, being market factors-constraints that need to be timely addressed, to enable the bankability and success of second-life PV business [24]:

- *Addressable volume towards market profitability*. As it was discussed earlier, the repairability of decommissioned PV modules is directly dependent on the type of failure/defect occurred during their (first) operational life. Service providers in this segment have to access and properly assess statistics and diagnostic data from PV O&M actors (e.g. failures' occurrence and severity, degradation rates, impact on system performance, correlation with plant characteristics and age), to be able to determine:
  - The target volume, i.e. the failed PV modules the repair of which is technically feasible, and the occurrence of repairable failures.
  - The age and share of these "repairable" PV modules, out of the overall volume of failed ones. For instance, PID issues are mainly reported through years three and four of operation, during which they may comprise up to 30-40% of reported failures. Bypass diodes and junction boxes failures are spread over the first 10 years of operation, with a share typically ranging between 15% and 25% of all reported failures.
  - The cost of the needed repair actions, i.e. whether the repair/refurbishment of certain PV modules makes sense cost-wise, considering current prices of new PV modules.

Next to the above, one should note that there is a considerable volume of fielded PV modules that, although being non-failed ("healthy"), are still decommissioned in view of economic and/or technical reasons, e.g. insurance claims, repowering or lack of spares. In principle, such modules (especially the "younger" ones) are considered as very promising candidates towards PV re-use (second-life) business. In this direction, systemising appropriate labelling as well as time- and cost-efficient characterisation and reliability/qualification testing comprise the central R&D gaps to be addressed.

- *Product efficiency and reliability towards market confidence*. In practice, the (remaining) efficiency of repaired/refurbished PV modules will depend on the years of their field exposure (thus power degradation rate), at the moment of the repair. In other words, efficiency-wise, repairing relatively "young" PV modules, i.e. with infant failures, has higher added-value potential. Besides, since PV modules in failed state degrade much faster [5], timely and efficient detection of failed (yet repairable) modules in a PV system is another critical aspect. Next to product efficiency, another major challenge towards the bankability of second-life PV business is the lack of market confidence or "trust" in the reliability (and safety) of refurbished PV modules. Evidently, the latter stems from the lack of relevant regulatory framework and standardised reliability testing, as it has been also discussed above. In fact, considering that a PV module's warranty is intrinsically lost once a refurbishment/repair action is conducted, there is a need to somehow "certify" that the repaired, second-life module is safe and can regain the trust of the end-user.

Finally, next to the above, the societal impact of second-life PV business and its market development shall be studied and quantified in view of its job creation potential. When looking into the value chain, PV re-use (and preparation for re-use, i.e. field inspections, repair/refurbishment, characterisation and reliability testing, as well as the R&D pathways towards PV designs-for-circularity, the second-life PV business case can be definitely associated with creations of jobs in a broad educational/technical range, e.g. technicians, field engineers, researchers in PV industry and research/academia.

Looking ahead

It is well understood that PV waste is becoming a pressing environmental matter and a new technical challenge for the PV industry; which, however, also actuates with new R&D opportunities, to prepare today towards sustainable EoL practices and circular economy-based services for the PV sector.

In this article, we have provided the research and technical groundwork towards the second-life PV business, outlining current best practices, market landscape and constraints. We have identified certain knowledge and regulatory gaps, which largely explain the scarcity and struggles of second-life PV market players on one hand, and the limited public awareness and confidence of (potential) end-users, on the other hand. In this regard, credible understanding and practical validation of performance, reliability and safety of second-life PV modules are instrumental for trust-building and opening up second-life PV markets.

With these in mind, our future work will focus on formalising the recycle, repair and re-use segments in the PV value chain, through the following main R&D pathways:

- assessment and validation of PV design-for-circularity concepts;
- development of tailored, cost-efficient reliability testing and characterisation protocols for both failed/repaired and "healthy"/decommissioned, second-life PV modules;
- cost-profit and lifecycle analysis for the PV re-use (second-life) business case. ■

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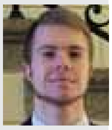

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Tools of the trade for corporate renewable energy buyers


Credit: EDF Renewables

Corporate PPAs | A new toolkit has been launched to support companies in Europe that want to meet more of their energy needs from solar and other renewable energy sources. As SolarPower Europe's Bruce Douglas explains, alongside much-needed regulatory reform the resource will help unlock the immense corporate renewables sourcing opportunity

Europe has set a target that 32% of its energy should come from renewable sources by 2030, up from 17.5% today. Corporates are key to achieving this target since they are responsible for almost three quarters of total final electricity consumption in the EU. Corporates – including from the steel, aluminium, ICT, and chemicals industries – can power their operations with renewable electricity and help to achieve the target. Facilitating access to renewable electricity for corporate consumers could deliver both significant reductions in CO2 emissions and make European industries more competitive, thanks to the rapidly falling cost of solar and other renewables.

Corporates have significant potential to boost the EU economy. A recent study from the European Commission shows that if EU-based industrial and commercial companies commit to meeting only 30% of their total electricity demand with renewables by 2030, they could generate more than €750 billion in gross added value and more than 220,000 new jobs [1].

Corporate sourcing of renewables has risen rapidly in Europe, with 7.5GW of power purchase agreement (PPA) deals signed over the past five years, and 1.6GW worth of deals in 2019 alone. More European countries are engaging in PPA deals: 13 countries have inked PPAs in 2019 so far. Commercial and industrial on-site corporate sourcing accounted for 3.4GW in 2018 and is expected to grow considerably in the next decade. Solar is now cost-competitive with conventional power and due to its flexibility can be installed on almost any surface.

Corporate sourcing of renewables such as solar will be a key driver for future greenhouse gas emission reductions

The benefits that can be accrued from corporate sourcing of renewables are vast and the market potential is growing rapidly. That is why, in 2017, SolarPower Europe together with WindEurope, RE100 (led by The Climate Group in partnership with CDP) and WBCSD established the RE-Source Platform, to drive the uptake of PPAs, renewable energy investments and increase the number of corporates buying renewable power from 100 to 100,000 [2].

It is in this context that 1,000 clean energy buyers and suppliers met in Amsterdam at the RE-Source 2019 event from October 2-3, for three days of discussions, B2B meetings, and peer-to-peer workshops on how to accelerate the uptake of renewable energy. The annual RE-Source Event is the largest and most influential corporate sourcing event in

Europe, gathering all the major PPA and on-site renewable energy players – from buyers to sellers to policymakers and more.

To further raise awareness of the advantages of renewable energy and help corporates, particularly new entrants, to navigate the market with confidence, the RE-Source Platform launched the Renewable Energy Buyer's Toolkit at RE-Source 2019 [3]. The Toolkit has been developed to provide information and resources to inform new entrant corporates about the market and offer guidance on how to facilitate deals. It contains several tools to help unlock the immense potential for corporate sourcing of renewables and to pave the way to a low-carbon society.

The Toolkit at a glance

The first component of the Toolkit is the report, 'Introduction to Corporate Sourcing of Renewable Electricity' [4], which provides an overview of different strategies a corporate can follow to procure renewable electricity in Europe. We present the strategies and business models, dividing them into two main categories according to the geographical location of the renewable installation: on-site models and off-site models. We describe the key features for each model, including their relationship to Guarantees of Origin (GOs), information on financial and greenhouse gas (GHG) accounting, if they provide additionality, among other things. We also chart an overview of the European countries in which each model is feasible, or where different models have been implemented. In addition, we provide real-world examples of projects to illustrate how the models have been applied in various markets.

The second component is the 'European Corporate Sourcing Directory' [5], which shows which models of corporate sourcing have been used where and which models we believe are possible to use in each member state. Specifically, what makes a model possible to use is the absence of regulatory and administrative barriers. In this context, governments can play their part in removing administrative hurdles for corporate sourcing of renewables and for on-site generation that exist throughout Europe.

The third component is the European Federation of Energy Traders (EFET) template contract, which is the first pan-European standard corporate PPA designed to help reduce transaction costs and facilitate the negotiation process between the parties involved. The EFET-endorsed standard corporate PPA is valid for all European countries and allows for both physical and financial PPAs with the proven Election Sheet approach allowing for flexible tailoring of the PPA to the needs of the companies involved. The agreement will be supported by legal opinions in key jurisdictions, as well as translated into other EU languages to ease its uptake across Europe.

For corporate buyers to gain more confidence in navigating this growing and relatively complex market – with numerous deal structures available that may be difficult to value – our partners and PPA experts will organise training academies to explain how to compare PPAs systematically and quantitatively.

We are also preparing a report on 'Risk Mitigation for Corporate Renewable PPAs', written by risk mitigating product providers, that will offer new entrant corporates information on how to mitigate risks and how to tailor their PPAs to behave more like conventional power contracts.

SolarPower Europe and the other co-founders will continue to develop the RE-Source Toolkit and disseminate it across Europe. The RE-Source Platform will update the Toolkit regularly with new case studies, update the Directory when there is any change in national and EU regulations, and provide more insights and tools to help unlock this huge corporate renewable energy opportunity.

Removing administrative hurdles

While the Toolkit can help facilitate corporate PPAs, EU governments must also play their part in ensuring that more companies are able to easily source renewables, by removing administrative hurdles for corporate renewable PPAs, and on-site and direct investments in renewable energy generation that exist throughout Europe. Under the new Renewable Energy Directive, European governments now have the duty to remove these barriers. Currently, only two of the draft National Energy and Climate Plans for 2030 even mention PPAs and none comply with the agreed legislation.

What is clear is that the market is primed for commercial and industrial on-site corporate sourcing and PPAs, with more and more corporates signing deals. Earlier this year, in partnership with the RE-Source Platform, the German renewables giant BayWa r.e. released its Energy Report, which provides up-to-date analysis of 1,200 European corporations' attitudes to renewable energy [7]. The findings reveal the immense approval of corporates concerning renewable energy, with 89% reporting that companies must play a leading role in facilitating the energy transition and 80% responding that the use of renewables resulted in a competitive business advantage.

Confirming these findings, in October, Google announced the largest corporate renewables purchase in history, increasing its worldwide portfolio of solar and wind agreements by more than 40% to 5.5GW, including an agreement for 130MW of wind power from Finland, and 82MW of solar power from Denmark. Amazon recently unveiled plans to reach 100% renewable energy by 2030. Heineken also revealed that it intends to entirely power its Spanish operations via a new utility-scale solar plant, to be developed by Iberdrola. And IKEA, which has long been committed to renewable energy, announced that it aims to generate more renewable energy than it consumes in its operations globally by 2020; indeed, it has already achieved this feat in Portugal since 2018.

With corporate attitude towards PPAs and on-site renewables at an all-time high, and record-breaking deals signed in the last year alone, the future looks bright for corporate sourcing of renewable energy. The Renewable Energy Buyer's Toolkit is the missing link that simplifies, standardises and optimises this innovative business model for the new energy world. ■

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Merchant renewables: a viable investment or a bubble fit to burst?

Post-subsidy solar | After several years with a moratorium on renewable energy incentives and no new build, Spain is seeing a new generation of projects being developed without subsidies as grid parity is achieved. Whilst this has encouraged an increase in renewable energy projects, it could be harmful to profits and have serious economic risks for investors. ÅF Pöyry Management Consulting's Javier Revuelta considers the potential risks of taking a long-lasting grid parity in Spain for granted, how to mitigate these problems, and why it's relevant to us all

The trajectory of Spain's post-subsidy renewables boom will hold important lessons for other markets reaching grid parity

Anyone who believes we are in the midst of a climate crisis will celebrate the recent increase in renewable energy projects, but policies must also ensure a secure energy supply and competitive end-user prices. In order to contribute to the new ambitious EU targets for 2030, the Spanish government has committed to more than doubling the current wind capacity, and multiply by eight times the solar PV capacity; it considers the use of new auctions to find bidders, as a complement to subsidy-free developments. These auctions are expected to include guaranteed prices which shield investors from future changes in market prices, for example if they fall due to the increasing number of renewable projects already planned and promised to the EU. Unfortunately, this means that the market is likely to reduce revenues as a consequence of a high cannibalisation effect; whilst some cannibalisation can be digested by current projects and still make them sufficiently profitable, it might be too high if all grid connection requests that have deposited guarantees and have been accepted by the grid operator effectively go forward.

Government auctions mitigate investment risks, but there are considerable economic risks for those who believe that the current 'apparent' or 'initial' grid parity will remain over the life of the project, and that future market prices will support the case for independent investments outside of probable future government auctions. Those risks only increase when you consider other challenges that would contribute to reduce the cannibalisation of market prices, such as: the development of interconnections; the rise of currently unprofitable storage; electric vehicles; and the many necessary regulatory changes which are likely to take years to develop.

If the Spanish government strives to achieve its commitments with the EU through the development of auctions, those who have already invested and expect the wholesale electricity market to remain at current levels are likely to encounter serious economic problems. Should the wholesale electricity market price drop, they should not expect the government to bail them out, stop the annual auctions for new entrants, or change the market model so that it suits their needs. The government will not rescue investors, nor will the EU change the market model it has just ratified, at least in the foreseeable future. These investors should also not rely on a sector 'collusion' to bid-up in hours of RES surpluses and otherwise depressed prices, not only because it is illegal, but also because it is materially impossible to orchestrate and is counterproductive given its negative effect on renewable exports to the rest of Europe.

Investors must seek robust analysis and advice to decide where to put their money. The big question for any investor with merchant exposure is what future prices will be. At present, despite much higher revenues than new projects' LCOEs (the average remuneration that a project requires over its lifetime), it is difficult to guarantee whether investments in merchant renewables in Spain will indeed reach attractive returns over the investment lifetime, or whether very high additional capacities supported by auctions will trespass the bursting point of today's investors. Potential return on investment will depend on several factors, including: the international price of gas and carbon emissions; the development of electric interconnections; the penetration of electric vehicles and storage; and the government's ability to meet its commitments to reduce greenhouse gas emissions.

Forecasting

As for any other sector, an investment decision is a sole responsibility of the investor, who can do their internal research or hire studies from third parties. There are two types of very different forecasts that investors need. Long-term forecasts are required for investment decisions, with or without proper hedging instruments. If an investor cannot live with the forecasted future or with a potential downside case, then it ought to not invest with merchant risk and instead wait for the next government auctions.

No forecast in any sector that can be trusted at 100% or even close to that, even looking at short periods of 2-3 years. Obviously, no forecast can consider precisely unexpected events, geopolitical decisions, the exact technology breakthroughs, social changes etc. In short, projections of experts cannot be trusted as an accurate forecast of revenues; but, it is not so much about getting an accurate forecast (that would be ideal, but that just doesn't exist), it is about building a solid view of the potential futures, the most probable ones, the drivers of upside and downside, the range of impacts and whether one can live with the reasonably lower end of potential futures; and ultimately, taking a risk based on individual investors' belief. It is more about what possible futures you prepare for, and how likely those futures are. Hire good advisors, even several advisors to understand their different views, and build your own view.

Aside from long-term forecasts, short-term, day-ahead and within-day forecasts will be required to maximise revenues from increasingly sophisticated markets, where continuous trading and participation in ancillary services will make the smartest plants make a few extra euros/MWh compared to passive asset managers. There is also an interesting aspect to consider around the type of pricing of asset management services, from all fixed annual fee per megawatt, or all variable fee per megawatt hours produced; because 'market curtailments' will increase, and there is some risk-sharing due to curtailments between the producer and the O&M provider. In a world where, for instance, 5 or 10% of the hours there is a wind surplus that cannot be fed into the power market, a renewable producer must choose how low a market bid they are willing to go to before they prefer to shut down their plant and save the variable O&M costs plus have the plant live a little bit longer through lower wear and tear of equipment. In this world, the bidding strategy of the asset owner in the spot market, the cost structure of the asset management services, and the expected output production net of the resulting market curtailments, are interlinked decisions in the puzzle.

Power purchase agreements

The PPA is definitely one of the most used instruments for merchant investments, at least under discussion because only a fraction of negotiations end up in a signed contract. A PPA is an insurance against power prices, or in other words passing the risk to another entity. So obviously you need an off-taker willing to take the risk at a fee which is acceptable by the buyer of the insurance (i.e. the solar producer). If the price of the insurance is considered too high by the producer (the PPA price is too low) then there is no agreement; conversely if the price is too cheap (PPA price is very close from the market expectations) then the off-taker doesn't want to commit to being stuck in a 10-year contract that can ultimately put them out of business. It is proving very difficult to agree on terms that are acceptable by both parties, it typically takes one year to negotiate a PPA if you are already experienced and know beforehand what type of PPA suits you. By the way, current PPAs that have been signed have gone as high as 15 years, but technical lifetime and business plans of solar typically reach 30 to 35 years, so even the longest PPA only hedges a share of the project lifetime revenues; generally just enough to get the banks onboard and finance some of the Capex.

Finance

Banks are not very sophisticated yet, and most banks by principle do not finance – at all – projects with full merchant exposure. Few banks in Spain, and not the two largest, finance with merchant risk. For the ones that do, you can expect strong downside conditions to size the debt, and mechanisms to get the money as early as possible in case of upside, so investors are generally left with money towards the end of the lifetime. There is little movement around 'junior' or 'mezzanine' debt, more expensive but cheaper than equity investments; perhaps it is a financing segment to explore. Keep in mind that banks have never needed to really understand power markets to finance renewable projects in the past, when they were backed by government incentives; so for banks to reach a solid knowledge allowing them to get some exposure to this volatile market is a very long process that very few of them have only just started.

Operations and maintenance choices

O&M needs to be the cheapest, or at least the best value for money. And also to get smarter; O&M providers will need to not only provide a cheap service of quality, but to use new digitalisation strategies to understand the best interactions with the market. In the near future, counterintuitively it may be best to do some maintenance works tomorrow at noon when solar resource is the highest, because the market will pay €0/MWh anyway!

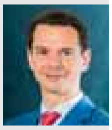
A risky future?

The future of the renewable energy landscape is unclear as we do not know how many renewable megawatts will be installed. At present, administrative inefficiencies and market price signals are the sole moderators of investors' appetites. In this new environment of subsidy-free developments, nobody controls and anticipates the volume of annual connections, and no authority is responsible for warning investors about the potential economic risks set out above.

A message for investors in renewables – regardless of where they are investing – is that it is not a responsibility for grid operators, governments or regional governments to show them the economic risks of their investments. Specialists must provide good analysis and advice to investors in order to help them understand the opportunities and the many risks. Investors should take care to understand this environment, or to otherwise entrust themselves to the wholesale electricity market.

At this point it's hard to say if subsidy-free investments in the renewable energy market in Spain will provide a good return on investment despite the very attractive initial returns of this 30 years investment journey. Hence investors must be aware of the potential risks. European governments can monitor the upcoming volumes of investments under the two main investment options (subsidy-free with volatile market revenues, or under auctions with guaranteed revenues), and we shall soon see whether they can learn from the Spanish energy market how to do things, or how not to do them. Business or bubble? Let's talk in 2030. ■

Author



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STORAGE & SMART POWER

Energy Storage NEWS

Introduction

As global politics appears to grind into some kind of populist eternal limbo, and the hounds of climate despair close in, the need for the renewable energy industry to maintain its customary level-headed, inclusive, forward-thinking attitude only grows.

More and more statistics and studies emerge that prove climate disaster and air pollution hell are already upon many of us, as if the evidence of our own eyes, noses and lungs were not enough. Yet, the mainstream press still publishes doubting voices and convenient untruths, it can't seem to help itself.

Increasingly, these climate deniers are analogous in so many ways to 'flat-earthers', that nutty 1 million-strong crust of folk that can't quite believe you can be standing on something spherical if it's large enough. Yet despite the illegitimacy of many of their views, and an undue emphasis on talk-show conspiracy over science, it can seem like those people are winning, sometimes.

However, if good ideas can have inflection points, we may well turn out to be living in the heroic years, where we simply got along with modernising an outdated energy system to be the most efficient it can be – and made a big environmental and social contribution simultaneously.

US Energy Storage Association CEO Kelly Speakes-Backman, a former public utility commissioner, is one of the people working to make that happen every day. With more than 180 member organisations, ESA is speaking up for a big wedge of stakeholders in the energy sector that see renewables and energy storage as a day-to-day business as well as an aspiration and social good.

Find out why energy storage may be one of the politically least divisive topics in the US today, and lots more besides, in our exclusive interview with Kelly (see page 120).

We're rapidly approaching the end of the year, and the limited hours of daylight I'm enjoying here in London make the need for seasonal energy storage an obvious one. From short-duration, fast-responding lithium batteries for ancillary services, the market for energy storage is changing beyond recognition as we speak.

Solar Media writer Alice Grundy and I profiled some of the promising long-duration energy storage technologies – and their champions – either on the market today and fighting to gain traction, or preparing for launch and drumming up a buzz around their 'unique' ideas and system configurations.

An excellent companion piece to that is the in-depth look at 'Redox flow batteries for energy storage', which comes from co-authors Jens Noack, Nataliya Roznyatovskaya, Chris Menictas and Maria Skyllas-Kazacos from CENELEST, a joint research venture between the Fraunhofer Institute for Chemical Technology and the University of New South Wales. The team look at the rise of various types of flow energy storage and what stands between them and greater success.

We really hope you enjoyed last edition's Special Report into Energy storage: Beyond the hype and similarly find plenty of interest in this quarter's 'Storage & Smart Power', from the team at Energy-Storage.news.

Andy Colthorpe
Solar Media

CATL wants to deliver LFP batteries for ESS at 'multi-gigawatt-hour scale' into Europe and US

CATL sold 21.31GWh of lithium batteries in 2018, primarily to the EV market in China, but after exhibiting at two major trade shows in the west, claims its 12,000 cycle lithium iron phosphate batteries are ready to take on the stationary energy storage system (ESS) market, too.

Contemporary Amperex Technology Ltd, to give CATL its full monicker, employs more than 24,000 people globally and claimed in May this year to have partnerships with "US-based top-tier solar companies" for 1.85GWh of batteries.

CATL presented its ESS division at US and European trade shows this year for the first time.

CATL is considered one of the few manufacturers capable of producing appropriate grid-scale energy storage systems using lithium iron phosphate (LFP) cells. At present this may be a competitive advantage in some US markets, due partly to recent RFPs from numerous utilities stipulating the use of LFP in preference to NMC cells based more typically on the energy-dense battery technologies used in electro-mobility applications.

Phoenix summer peak load to benefit from 1GWh solar-battery system

Phoenix-based community utility Salt River Project (SRP) is to build the largest solar-plus-storage project in the southwestern US state of Arizona, just as a historic coal plant is put to rest.

Two new solar and battery projects, to be owned and operated by subsidiaries of NextEra Energy Resources, will help the utility reduce emissions and tackle the summer peak load using the battery storage technology. The investment makes SRP one of the largest energy storage investors in the country and the non-profit claims that it continues "aggressively pursuing renewable generation".

The Sonoran Energy Center will have a 250MW solar array charging a 1GWh energy storage system in Little Rainbow Valley, south of Buckeye. Meanwhile, the Storey Energy Center will include 88MW of solar alongside an energy storage system scheduled to be built south of Coolidge.

Second life lithium battery storage in Kenya to come in at 'half the cost' of lead acid

Lithium-ion waste from a solar lantern scheme run by oil & gas major Total in Kenya will be recycled into new batteries for solar home systems by start-up Aceleron.

Total Access to Energy Solutions (TATES) sells solar lamps and kits in emerging markets and aims to sell 6 million distributed "solar energy decentralised solutions for homes and communities" by 2025, which would enable electricity access for roughly 25 million people.

The initial £51,000 (US$65,910) project between the two sees UK-based Aceleron turn TATES' lithium waste into second life batteries at US$45 per kWh. Over a predicted lifespan of seven more years in the field those particular batteries could have, this works out at US$6.5 a year in Kenya, where, Aceleron claims, lead acid can already cost almost twice that (US$12 a year per kWh) and only last for three years.

Germany's grid could use gigawatt-scale ESS as alternative to 'billions in infrastructure spending'

A portfolio of 1,300MW of energy storage recommended for Germany's transmission networks in a grid development plan for enhancing network stability, could save transmission networks "billions of dollars."

A report produced by the utilities that own those networks shows that batteries can be used to "mimic" the roles of existing assets in the electricity network.

In the 'Grid-Booster' project, grid stability can be aided and network costs potentially lowered by adding that huge portfolio of energy storage. Instead of building a separate, third transmission line for backup transmission capacity (the N-1 grid reliability standard which allows for redundancy), two utility-scale energy storage systems, will be placed at either end of the two operational transmission lines. Obviating the cost of operating the third line while rarely using it, if ever, could enable greater efficiency being wrung from existing power transmission infrastructure.

China to 'dominate recycling and second life battery market worth US$45bn by 2030'

While recycling of lithium and other materials such as cobalt from batteries will greatly increase in the coming years, the potential availability of second life batteries should not be underestimated, according to new research and data.

Consultancy Circular Energy Storage predicts that "more than 1.2 million tonnes of waste lithium-ion batteries will be recycled worldwide by 2030". By then, the amount of recycled lithium available to the global battery supply chain will be equivalent to about half of today's lithium mining market, while the amount of recycled cobalt in 2030 will be around a quarter of today's equivalent.

Between 2019 and 2030, close to 1,000GWh of "remanufactured and second-life batteries" will be in use worldwide. With China expected to dominate lithium recycling efforts – as well as being a likely contributor of some 57% of lithium battery waste by 2030 – it's also likely the country will "take a tighter grip on" recycling and recovery and will also be the biggest source of second life batteries by volume, consultant Hans-Eric Melin said.

California offers extra solar, storage incentives after wildfires and shut-offs

Communities most likely to be affected by both the effects of and the response to devastating wildfires which have wreaked havoc on California will be given extra incentive to install solar-plus-storage at their properties.

In addition to the impact of the fires themselves, the latter part of this year saw utility PG&E, already facing bankruptcy proceedings relating to liabilities for previous fires, shut off power to more than a million people in areas where outlying substations, wires and cables from the grid are mapped out to be at risk from high winds and falling trees.

The California Public Utilies Commission has now made some adjustments to the state's Self-Generation Incentive Program (SGIP) to incentivise distributed generation - and storage - adoption.

Redox flow batteries for renewable energy storage

Battery storage | As energy storage becomes an increasingly integral part of a renewables-based electricity system, new technologies are coming to the fore. Jens Noack, Nataliya Roznyatovskaya, Chris Menictas and Maria Skyllas-Kazacos from CENELEST, a joint research venture between the Fraunhofer Institute for Chemical Technology and the University of New South Wales, chart the rise of redox flow batteries, a promising alternative to lithium-ion-based systems

In the last 15 years, the increase in renewable energy sources such as photovoltaic and wind energy has accelerated significantly. At the same time, manufacturing and installation costs, especially for PV systems, have fallen significantly, making this energy source one of the cheapest and cleanest forms of energy, depending on the location. With the increase of fluctuating renewable energies in an electrical grid, the need for compensation possibilities at times when renewable energies are not available increases [1]. One possibility is the use of electrochemical energy storage such as lithium-ion, lead-acid, sodium-sulphur or redox-flow batteries. Additionally, combinations of hydrogen electrolysis and fuel cells can be used [2]. Batteries can be adapted in a flexible and decentralised manner depending on the respective requirements and are scaleable from a few kW/kWh for e.g. domestic storage up to systems of several MW/MWh for grid storage. The different types of electrochemical energy storage systems have different physical/chemical properties, which affect the cost of the system. It is important to note that the cost of the storage system over its lifetime (levelised cost of storage – LCOS) is a critical factor used in selecting the most suitable system for a particular application [3]. For example, the investment costs for lead-acid batteries are significantly lower than for all other technologies, but the service life is very short.

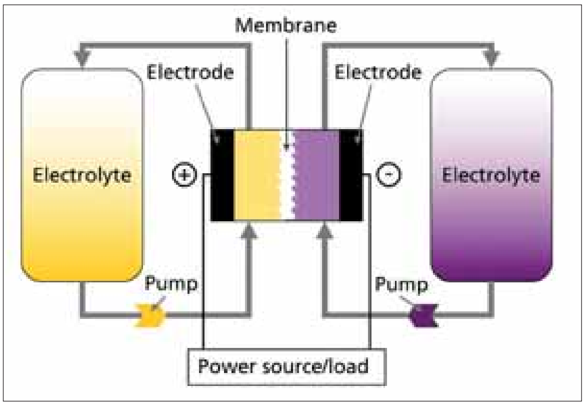
Technologies with similar investment costs at higher lifetimes result in a lower levelised cost of storage, but to be precise additional factors such as recycling, energy efficiency and maintenance costs have to be considered. A battery with a high efficiency, low recycling effort, low investment and maintenance costs and great freedom of scalability to meet the requirements of the application would be an ideal system. In electrical networks there are different storage time requirements: short-term storage, medium-term storage and long-term storage. The shorter the storage time, the more suitable are physical storage devices such as capacitors. Batteries are suitable for applications ranging from a few minutes to several hours. In addition, mass storage systems such as electrochemical hydrogen generation (power-to-gas) are particularly suitable for long-term storage of several weeks.

Redox flow principles

All electrochemical energy storage systems convert electrical energy into chemical energy when charging, and the process is reversed when discharging. With conventional batteries, the conversion and storage take place in closed cells. With redox flow batteries, however, the conversion and storage of energy are separated [4]. Redox flow batteries differ from conventional batteries in that the energy storage material is conveyed by an energy converter. This requires the energy storage material to be in a flowable form. This structure is similar to that of fuel cells, whereby in redox flow batteries, charging and discharging processes can take place in the same cell. Redox flow batteries thus have the distinguishing feature that energy and power can be scaled separately. The power determines the cell size or the number of cells and the energy is determined by the amount of the energy storage medium. This allows redox flow batteries to be better adapted to certain requirements than other technologies. In theory, there is no limit to the amount of energy and often the specific investment costs decrease with an increase in the energy/power ratio, as the energy storage medium usually has comparatively low costs. Figure 1 shows the general operating principle of redox flow batteries. The energy conversion takes place in an electrochemical cell which is divided into two half cells. The half cells are separated from each other by an ion-permeable membrane or separator, so that the liquids of the half cells mix as little as possible. The separator ensures a charge balance between positive and negative half cells, ideally without the negative and positive active materials coming into direct contact with each other. In fact, however, separators are not perfect so some cross-over of the active materials always occurs and this leads to the self-discharge effect.

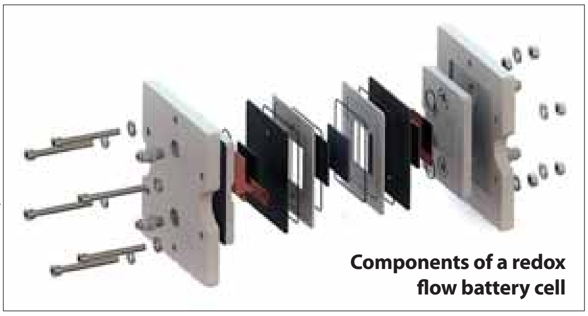
In a single cell there is always one positive and one negative half-cell. The electrochemical reactions for charging and discharging take place at the electrodes of the half-cells. The electrodes are the phase transitions of ionic and electronic conductors. In redox flow batteries, the electrodes should not participate in the reactions for energy

Schematic of a redox flow battery



Credit: Fraunhofer ICT

Credit: University of New South Wales



Components of a redox flow battery cell

conversion and should not cause any further side reactions (e.g. undesirable gas formation). Most redox flow batteries are therefore based on carbon electrodes.

The difference between the voltages of the positive electrode and the negative electrode is the cell voltage and is between 0.5 and 1.6V in aqueous systems. During the charging process, ions are oxidised at the positive electrode (electron release) and reduced at the negative electrode (electron uptake). This means that the electrons move from the active material of the positive electrode to the active material of the negative electrode. When discharging, the process reverses and energy is released. The active materials are redox pairs, i.e. chemical compounds that can absorb and release electrons.

In redox flow batteries, the energy storage medium is often referred to as an electrolyte. However, there are redox flow batteries that use a gas that is not an electrolyte (e.g. H/Br-RFB) as with hydrogen. As with all other aqueous batteries, aqueous energy storage media from redox flow batteries are also subject to water limitations. In case of too high voltages or more precisely too high or too low half-cell potentials, the water is decomposed into its components, hydrogen and oxygen. The generation of hydrogen in particular is often present as a very small but undesirable side reaction and causes a charge carrier imbalance between positive and negative half-cells, which leads to a slow loss of capacity. Due to the flowability of the energy storage medium, the reaction products that would normally remain in the half-cell can be transported out of the cell and stored in separate tanks thus allowing the capability for a higher capacity than that attainable with conventional batteries.

Hybrid redox flow batteries

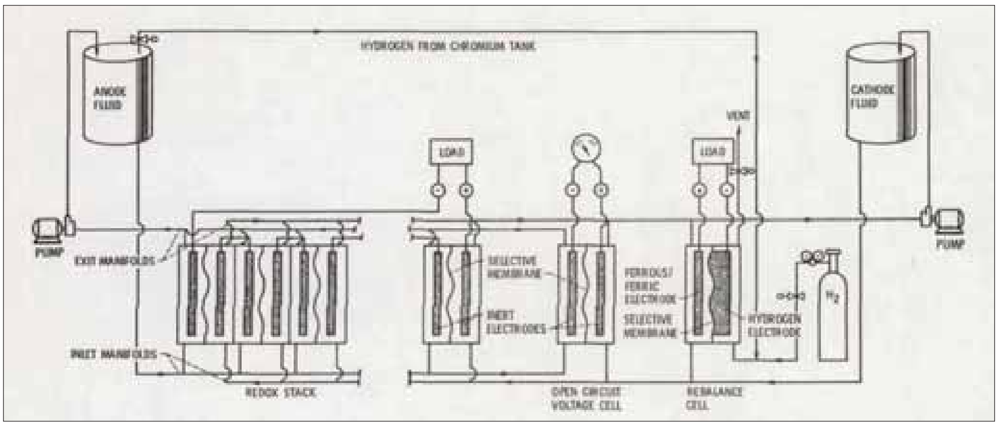
In redox flow batteries there are normally no phase transitions with solid active materials as with other batteries. This can significantly increase battery life because no lattice structures have to be rebuilt each time the battery is charged or discharged, and all materials are in a solution. The best known representative of redox flow batteries today is the vanadium redox flow battery. However, there are also flow batteries in which solids are deposited and dissolved at one or both electrodes. A typical representative is the zinc/bromine redox flow battery and patented in 1885 by Charles Bradley [5]. Such batteries are called hybrid redox flow batteries. In contrast to redox flow batteries, power and energy are not separately scalable, as the amount of possible solids deposition is limited by the cell geometry.

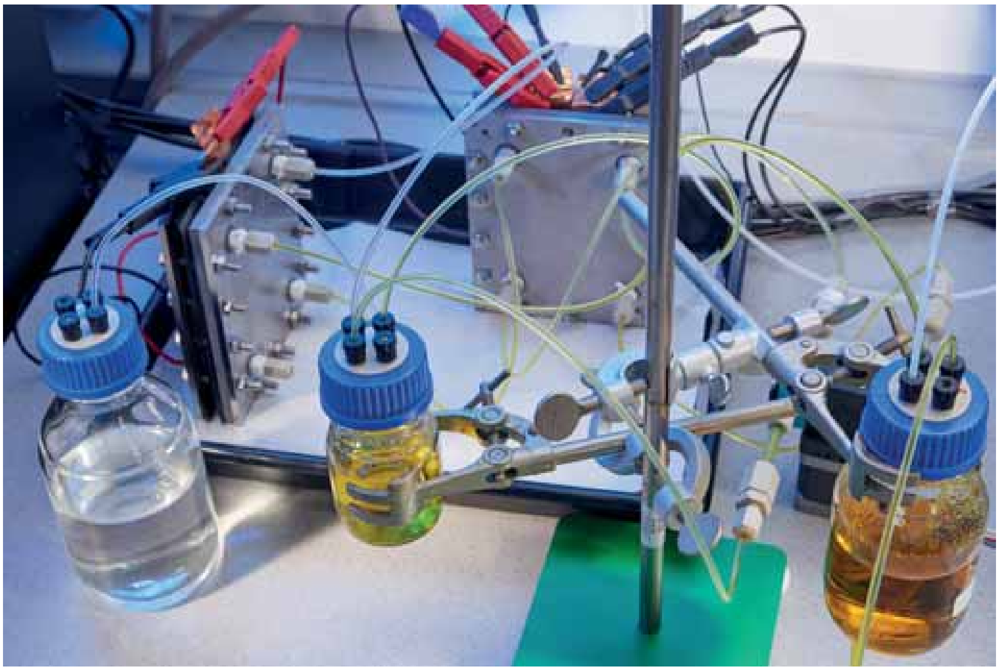
Hybrid redox flow batteries also usually have two electrolyte circuits like conventional redox flow batteries, but too much active material would lead to a too-thick layer of solids in the half-cell and thus to clogging of the fluidic system or to so-called dendrites, which are uneven deposits and can lead to short circuits through the separator. As with all other batteries, however, the power density decreases with the layer thickness of the half cells. For this reason, the space for the deposition and thus the layer thickness is optimised with regard to the power density and usually leads to storage times of approximately 4-8 hours. The advantages of the Zn/Br redox flow battery are the low costs of the active materials, zinc and bromine, and the high energy density of approximately 70-80Wh/litre. The disadvantages are above all the use of bromine and the relatively short cycle life with several thousand charging and discharging cycles. Elementary bromine is produced when charging the battery at the positive electrode. In order to reduce the risk potential and self-discharge, organic complexing agents are added to the energy storage medium to bind the bromine and prevent it from escaping [6]. The complexing agent is relatively expensive and the subject of research to reduce battery costs. The used redox pair Br/Br- has a very high reaction speed and is ideal for batteries from an electrochemical point of view. In the 1970s, Exxon and General Electric launched relevant commercialisation efforts in the USA and led to stack concepts, materials and production technologies that are still relevant today.

Later, starting in the 1980s, commercialisation efforts were made mainly by ZBB Corp. Australia, which developed modular multi-megawatt battery systems but stopped working a few years ago. In the 1980s, developments were also made for use in electric vehicles, primarily by the Austrian companies SEA and Powercell. The batteries were used experimentally in various commercial vehicles and buses. A vehicle with a Powercell battery finished first in the EV Division of the 1994 and 1995 World Clean Air Vehicle Rallies in California [7] Today only one company is selling Zn/Br-RFBs.

The first redox flow batteries were patented by Kangro in 1949 [8]. Kangro's motivation was, at that time, storing energy for wind and tidal power plants. Kangro's patent includes redox flow batteries based on the elements chromium, iron, titanium and chlorine. None of these systems have ever made it into commercialisation due to toxicity or technical problems. Pieper, a PhD student of Kangro, worked again on redox flow batteries in his doctoral thesis at the end of the 1950s [9, 10]. Pieper systematically investigated the potential of many inorganic active materials for applications in redox flow batteries. It is interesting to note that he also included vanadium in his considerations, but based on literature searches in which

Schematic of an iron/chromium redox flow battery system [13]





Credit: Fraunhofer ICT

side reactions, in particular hydrogen development at platinum electrodes, were reported, he ruled out suitability. Pieper later used carbon electrodes, however, that standard material, which is also used today for vanadium redox flow batteries, in his experiments with other active materials. A vanadium redox flow battery would have been possible with his experiments as early as the 1950s. However, Pieper favoured a titanium/iron redox flow battery, which was later further developed by NASA [11].

The Ti/Fe-RFB uses Fe^{2+}/Fe^{3+} as negative and Ti^{3+}/TiO^{2+} as positive redox pair. The reactions of Fe^{2+}/Fe^{3+} are very fast, but the reactions of Ti^{3+}/TiO^{2+} are much slower, which makes the energy efficiency and power density relatively low. The Ti/Fe-RFB has the disadvantage of a low cell voltage of about 0.8V and a low concentration of active materials. The maximum achievable energy density is thus approximately 10Wh/L and practically much lower. For these reasons the Ti/Fe-RFB has never been successful.

With the beginning of the first oil price crisis in 1973, a rethinking of the energy supply began. Investments in regenerative energy sources and the necessary research and development of storage systems for fluctuating energy producers led to the development of the iron/chromium redox flow battery at NASA by Thaller [12]. Thaller was also the first to use the term "Redox Flow Cell". In the Fe/Cr-RFB, as in the Ti/Fe-RFB, the redox pair Fe^{2+}/Fe^{3+} is used, but on the positive electrode. As already mentioned above, the reaction rate of the redox pair is high and thus are the achievable power density and energy efficiency. Iron is also an extremely inexpensive material for energy storage. By far the greatest challenges occur with the reactions of chromium ions at the negative electrode. The redox reactions of Cr^{2+}/Cr^{3+} are very slow and are close to hydrogen generation, so the efficiency of the reactions is very low.

NASA's work was therefore primarily concerned with these reactions and their acceleration by catalysts and the suppression of hydrogen formation by inhibitors. Prior to this, however, there was again a screening of possible candidates as active materials for redox flow batteries. Again, vanadium was considered on a theoretical basis, but ultimately due to the cost was not further studied. Iron and chromium were selected because of potentially low costs [14]. NASA's work led to a demonstration system with an output of 1kW/13kWh as a domestic storage system coupled with a PV system [15] and lasted until around the mid-1980s. With the lowering of crude oil prices, the general interest in renewable energies and storage facilities decreased so that no commercialisation took place. It was not until the mid-2000s that various companies attempted to commercialise Fe/Cr-RFBs again, but these were discontinued.

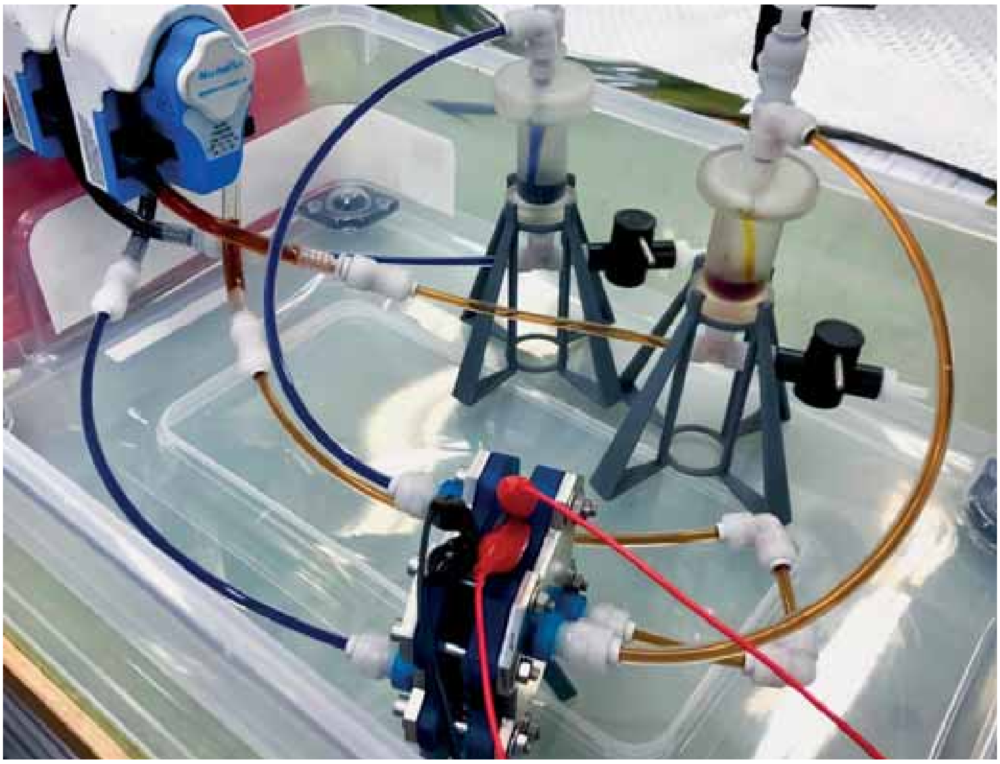
Iron/iron redox flow battery

In 1981, Hruska and Savinell published an article about a hybrid redox flow battery that only uses iron as an active material [16]. The motivation was the use of an energy storage material that was as inexpensive as possible, which is almost unsurpassable with iron. One kilogram of iron corresponds to approximately 500Wh, or 1kWh would cause approximately US$5 in active material costs. The Fe/Fe-RFB uses the soluble redox pair Fe^{2+}/Fe^{3+} at the positive electrode but the redox pair Fe/Fe^{2+} at the negative electrode just like the two iron-based RFBs discussed above.

The initial solution is a relatively simple and widely available Fe(II) salt solution, similar to that used on a large scale in wastewater treatment. Solid

Credit: University of New South Wales

Colours of different oxidation states of vanadium from left to right: VO_2^+, VO^{2+}, V^{3+}, V^{2+}



Credit: University of New South Wales

Laboratory bench-scale vanadium redox flow battery

and elemental iron is deposited on the negative electrode during charging and dissolved again during discharge. The challenges with this battery are the hydrogen generation at the negative electrode and the low reaction rate of Fe/Fe^{2+} at the negative electrode. The generation of hydrogen leads to a significant loss of capacity, which can, however, be prevented or reversed by appropriate measures. The low reaction rates result in low efficiency, which can be increased by operating at elevated temperatures between 50-80°C. The low reaction rates result in low efficiency. The energy efficiency is approx. 60-70%, but it should be noted that energy efficiencies must be considered in connection with the application. The potentially low investment costs of the battery, together with compensation for losses from low-cost renewable energy, can result in a lower levelised cost of energy than other storage technologies. In the last 10 years, research and commercialisation activities have increased, albeit at a very low level.

Vanadium redox flow batteries

At about the same time as NASA's developments came to an end, the University of New South Wales conducted investigations into vanadium ions as an active material for redox flow batteries. Maria Skyllas-Kazacos et al finally found the possibility of using four different oxidation states on carbon electrodes in fundamental electrochemical

Stacks of a 2MW/20MWh vanadium redox flow battery at Fraunhofer ICT

investigations [17, 18] and later as battery experiments [19].

In the following years, almost all aspects of the vanadium redox flow battery (VRFB) were investigated at the UNSW. Efficient manufacturing processes were developed from inexpensive and widely available raw materials for the active material, the electrochemical and chemical basics were investigated, the energy density was increased through the use of concentrated solutions and stabilising agents, inexpensive separators and membrane modification methods were investigated and the power density was increased through electrode treatment processes. Stack cost reduction was also achieved by the development of an inexpensive conducting plastic bipolar electrode substrate that can be welded to the cell flow frame. In 1989, the work led to a battery with 1kW power and its performance was reported in 1991 [20]. This was followed by the installation of a 15kWh VRFB by the UNSW team in a Solar Demonstration House in Thailand and the licensing of the UNSW patents and technology to Mitsubishi Chemicals/Kashima Kita Power Corporation (MC/KKEPC), Japan in 1994. This was followed by a five-year R&D collaboration programme between UNSW and MC/KKEPC that led to the installation and testing of a 200kW/800kWh VRFB at Kashima Kita in 1995. In the following years, more and more work was carried out by other research groups and further commercialisation trials were carried out by UNSW's licensees. Particularly from the 2000s onwards, interest in research and industry increased sharply.

Today, the vanadium redox flow battery is without doubt the best investigated and most installed redox flow battery. Numerous patents and publications cover almost all aspects of the vanadium redox flow battery (VRFB). The VRFB uses only vanadium as an active material in three different oxidation states. The redox pair VO^{2+}/VO_2^{+} at the positive electrode and the redox pair V^{2+}/V^{3+} at the negative electrode. The use of the same ions in the positive and negative electrolytes permits relatively high concentrations of active material. This allows the classical VRFB to keep up to approximately 1.8mol/L vanadium in solution and thus achieve maximum energy density of up to approximately 38Wh/L. Vanadium is a relatively frequently occurring metal that is enriched as a by-product during the combustion of fossil fuels. Its main application is as an alloying metal for steel production. By using vanadium ions in solution, potentially very high cycle lifetimes can be achieved, as no complex phase transitions and new phase build-ups are necessary.

A further advantage is the simple recyclability of the batteries. Due to the high content of vanadium in the liquid electrolyte, the vanadium can easily be reintegrated into process chains and the existing value reused. The energy storage solution consists primarily of vanadium sulphate in a diluted (2mol/L) sulphuric acid containing a low concentration of phosphoric acid and is therefore roughly comparable to the acid of lead/acid batteries. The energy density is limited by the concentration of the pentavalent VO_2^+. Unfortunately, pentavalent vanadium ions have a tendency to react with each other, which leads to the formation of larger molecules which precipitate as solids and can thus damage the system. The reaction depends on the temperature and the concentration of VO_2^+ (state of charge), but is also a function of the proton concentration. Increasing the acid concentration increases the stability of VO_2^+, but this reduces the solubility of the V(II), V(III) and V(IV) sulphates. The vanadium and total sulphate concentrations are thus set at around 1.8 and 4.2mol/L respectively in order to achieve an acceptable operating temperature range. With a high state of charge and elevated temperature, the tendency to form solids in the positive half-cell increases, which is why the electrolyte temperature is usually limited to a maximum of 40°C. To minimise the risk of precipitation of the other species at low temperatures, a lower limit of 10°C is usually recommended. Alternatively, the SOC limits can be adjusted to handle temperatures outside this range.

Like all other RFBs, VRFBs also have a battery management. A battery management ensures optimum and safe conditions for battery operation. Often a heat management system is integrated to avoid too high or too low temperatures. The classic VRFB has undergone several further developments. First, the V/Br-RFB called Gen 2 was developed by Skyllas-Kazacos et al. at the UNSW [21].

By using the fast redox pair Br_2/Br^-, the objectives were a higher energy density and a better temperature stability, as well as possibly higher energy efficiency. Gen 3 was developed at the Pacific North West National Laboratory (PNNL) and uses a mixture of hydrochloric acid and sulfuric acid as solvent for the vanadium ions [22]. This increases temperature stability and energy density up to 50Wh/L. A disadvantage is the internal formation of chlorine gas in the system, which has a higher demand on the stability of materials. Vanadium/oxygen cells are referred to as Gen 4, in which vanadium ions are oxidised by oxygen (e.g. from the air) during discharge and energy can thus be generated. The process is reversed in the charging process. Theoretically up to 150Wh/L energy density can be achieved [23]. Today's VRFBs range from a few KW/

KWh to several hundred MW/MWh. The applications range from home storage to industrial plants as large storage units in the grid. Several companies sell VRFBs today in different size classes.

Commercialisation and ongoing research

From the 2000s onwards, the number of scientific publications and commercialisation efforts for RFB types other than those mentioned here increased significantly. Basically, there are many possible combinations for inorganic RFBs. By 2015, there were about 78 different types of RFB, but only a few of them have or will ever have commercial relevance [4]. Of the many different combinations, Pb/Pb- and Zn/Ce- and H/Br-RFBs were the most studied in addition to the ones mentioned above [24, 25, 26]. The major challenges for new aqueous inorganic RFBs are above all the electrochemical window limited to a maximum of 2.1V, in which the redox pairs can function largely without hydrogen and oxygen formation, side reactions of the redox pairs with the solvent water and costs of the active materials. Especially the limitation of the voltage by the use of water led to investigations on the use of non-aqueous alternative solutions and redox pairs. The maximum possible voltage correlates with the maximum possible energy of an RFB. Doubling the voltage to 4V, as with lithium-ion batteries, doubles the maximum possible energy density. However, it should be noted that the cell resistance significantly determines the real energy density and often only very low energy densities can be achieved with very high cell resistances. Liu et al at the University of Michigan trialled the approach of using organic solvents to increase the energy density for the first time in 2009 with a vanadium-based organic acetylacetonate complex in acetonitrile [27]. Cell voltage versus aqueous inorganic VRFB increased from 1.6V to 2.2V.

The same group also showed potential for non-aqueous chromium and manganese-based RFBs [28, 29]. In 2011 also, the concept of a lithium-based RFB attracted attention [30]. As with conventional lithium-ion batteries, solids were used for the anode and cathode. To make the active materials flowable, they were used as suspensions in an organic liquid. Suspensions are mixtures of solid and liquid components. The authors expected energy densities of up to 250Wh/L. In the following years many different concepts of Li-RFBs have been investigated, but it is not known that commercialisation efforts have ever been made. It is likely that the costs associated with low cycle life and low current density are the reasons why there has been little work in the field in recent years.

The first completely organic RFB, i.e. organic redox pairs and organic solvent, was presented in 2011 by Li et al [31]. The advantage of a fully organic battery lies in the potentially low cost of organic active materials, their high availability and ease of disposal. However, organic solvents have an increased risk potential due to their flammability, and only low power densities can be achieved due to their low conductivity. These reasons in turn led to a focus on aqueous organic RFBs. The first organic RFB based on water as solvent and organic redox pairs was published in 2014 by Yang et al [32]. The authors used modified quinone and anthraquinone as active materials, substance classes that also occur as natural dyes. In the following years the research activity in the field of organic, especially aqueous RFBs increased significantly.

The multitude of possibilities for organic active materials is considerably higher than for inorganic RFBs. However, there are also limits, so that the molecules must not be arbitrarily large, because otherwise they would have a too high mass and thus low energy density. However, organic molecules also offer the possibility of several electron transitions. In the case of inorganic active materials, one electron transition or two electron transitions are usually used. A doubling of the number of electron transitions leads to a doubling of the capacity (Ah) and with the same properties a doubling of the energy density. However, organic RFBs can potentially have up to six and perhaps more electron transitions. However, the reactions of organic active materials are often very complex and side reactions can lead to a small but continuous loss of capacity. The transfer of the results from research is not easy, since often only small concentrations and quantities of active materials are used and the properties in real batteries can be completely different. These can be e.g. deposition effects on electrodes which reduce the power density or limit the capacity or a gradual destruction of the active materials. Although the advantages are clear, there is still a long way to go for a practicable use of organic RFBs.

Sunlight can be stored directly in chemical energy by means of photocatalytic reactions. The best-known processes are natural photosynthesis and the artificial photolysis of water into hydrogen and oxygen. The objectives are to reduce the number of conversions through more compact systems and to increase the compactness of the systems. In 2014, Liu et. al. showed an approach in which a VRFB with a suitable catalyst and a transparent positive electrode can use light with a yield of up to 12% directly to charge the battery [33]. At present, however, these investigations are still very much basic research.

RFBs have experienced highs and lows throughout their history. The reason for this is that the idea was usually ahead of its time and the intended use, i.e. the stationary storage of energy, was not

Tanks of a 2MW/20MWh vanadium redox flow battery at Fraunhofer ICT

Credit: Fraunhofer ICT

given to the extent required to develop competitive products. With the significant increase in renewable energy in the last 15 years, however, the situation has changed significantly. It cannot be foreseen that lithium-ion batteries will be the technology that will take over mobile and stationary tasks at low cost. Lithium-ion batteries currently lead to social problems (cobalt mining in the Congo), hazards (fire) and problems with the very expensive recycling (environmental aspects) of the many hazardous substances (cobalt, nickel, organic electrolytes). Lithium-ion batteries do not seem to be a sustainable and green technology currently. The demand for stationary storage facilities is growing every year and so is the demand for electric mobility. The costs of RFBs, especially VRFB and Zn/Br-RFB, have also fallen significantly over the last 10 years. These price reductions, however, still took place through the installation of comparatively few storage devices, mainly for demonstration plants. With an increase in the number of units and thus possible economies of scale and an optimisation of production towards mass production, further significant reductions in RFB's costs can be achieved. ■

The Fraunhofer ICT and University of New South Wales are working together as an alliance to intensify research activities in the field of electrochemical energy storage and to establish a joint international research centre – CENELEST – at UNSW. The aim is to strengthen expertise in redox flow batteries and to develop other types of batteries and fuel cells in order to cover the entire range of electrochemical energy storage needs for renewable energy.

Authors

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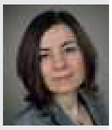
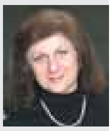


Nataliya Roznyatovskaya studied chemistry at the Moscow State Lomonosov University and completed her PhD in 2005 on the mechanisms of the electrochemical reduction of binuclear metal–ligand complexes. After postdoctoral research at the University of Regensburg, she became scientific Associate in the Department of Applied Electrochemistry at the Fraunhofer ICT. Her research focuses on the electrochemical investigation of electrolytes for electrochemical storage and conversion.

Chris Menictas is an associate professor in mechanical and manufacturing engineering at UNSW Sydney Australia. His research interests include: design, modelling and prototyping of flow battery and fuel cell systems; development of temperature modulating devices for bio-medical applications, air conditioner design optimisation; and thermal morphing. He is head of the Energy Storage and Refrigeration Laboratory at UNSW Sydney Australia.



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Contenders: Long-duration technologies and who's behind them

Technology | While lithium-ion batteries get most of the headlines, long-duration energy storage solutions are gaining ground. Alice Grundy and Andy Colthorpe profile some of established and emerging concepts in this this increasingly important class of storage technologies

As the global energy market, piece by piece, slowly but surely, moves towards a renewables-centred paradigm, dispatchable solar and uncurtailed wind, along with other forms of clean energy, are requiring longer and longer durations of storage to integrate them to the grid. While there'll be a place for lithium-ion for many years yet, the technology really excels at applications of up to around four hours. For everything else, there's a growing list of contenders, with diverse technologies and at different stages of commercialisation. Here's a handy guide to some of those technologies and their providers, electrochemical and otherwise, that promise anything from five hours to even days or weeks of storage.

Credit: Denis Egan/Wikimedia Commons

Pumped hydro plants such as Dinorwig (pictured) have a long legacy of providing energy storage.

Who's got a head start

Pumped hydro

It's worth remembering that more than 90% of the world's installed base of energy storage in megawatt-hours is still pumped hydro. Lithium-ion may take the plaudits and the new market share today, but historically, the legacy of pumped hydro remains huge.

Water is elevated using pumps into a retained pool behind a dam. When electricity is required, the water is unleashed and runs through turbines, which then creates electricity. While the amount of energy required to pump the water back up is far less than the amount generated as it falls, systems can also be paired with renewable generation to pump the water back to the top.

However, while the system is cheap once built and can last for many years, finding appropriate sites and getting permission to build pumped hydro plants remains an obstacle to widespread further development in most parts of the world.

In June 2019, Australia-based firm Genex Power announced it was set to receive a second round of debt funding from the Northern Australia Infrastructure Facility (NAIF), for what will be the world's first pumped hydro project to utilise an abandoned gold mine.

In Chile, a 300MW pumped hydro project is under development, having recently received an injection of US$60 million in fresh funding from the Green Climate Fund. The Espejo de Tarapacá project, which will also see a 561MW solar PV plant, is being developed by Chilean renewable developer Valhalla and construction is set to begin next year.

French energy giant Engie is also a proponent of the technology, with its First Hydro Company owning the Ffestiniog and Dinorwig pumped hydro assets in Wales. Engie lauds Dinorwig as the fastest power generation asset in the UK, with the ability to deliver 1.7GW in 16 seconds.

Sodium-sulfur (NAS) batteries

Also fairly well established today, Japanese firm NGK has been working on its NAS sodium-sulfur batteries for

Credit: NGK Insulators

20MW of NGK NAS batteries, deployed as part of a huge 648MWh project in Dubai

over three decades. R&D of the Beta Alumina electrolyte, a key component of the system, began in 1984, with the development of the NAS itself beginning in 1989. NGK worked in collaboration with Japanese energy giant TEPCO for the development of the technology and is the only maker of large-scale sodium-sulfur batteries.

The batteries have a six-hour discharge at rated output and between 14 and 18 hours at one-third rated output. A project completed this year in Abu Dhabi, the capital of the United Arab Emirates, demonstrated the technology's six-hour duration, with 15 systems totalling 108MW/648MWh

The battery has a relatively high upfront cost versus lithium, but the longer duration gives it an edge, as well as its potential scalability, which puts it ahead of flow batteries, the company claims.

Two types of units are on offer from NGK: the plug-and-play style system consisting of four container subunits, each of which includes six NAS modules, each of those rated at 33kW/200kWh, is one such unit. The second, package type unit, has a rated output of 1,200kW/8,640kWh, made up of 40 NAS modules, each rated at 30kW/216kWh.

With an expected lifetime of 15 years, the system is set to see 4,500 cycles, making that 300 per year.

As is perhaps evident from the name, the two active materials of the battery are sodium and sulfur. The positive electrode houses the sulfur, the negative electrode the sodium. A third component, Beta Alumina ceramic, is mounted between the sodium and sulfur as the electrolyte. The active materials are liquid, the electrolyte a solid.

NGK, which has a background in industrial ceramics, opened a plant in Aomori, Japan in 2008 with a capacity of 34MW/245MWh, co-located with a 51MW wind farm owned by Japan Wind Development, helping to stabilise the wind output, as well as contributing to the farm meeting the server grid code of Tohoku Electric and selling the electricity to Japan Electric Power Exchange. Much more recently, it sealed a partnership deal with chemicals giant BASF for the provision of NAS batteries.

Flow batteries

Unlike some of the others in this list, flow batteries are being delivered by a number of companies. And while the industry has

They may look like other batteries in the field, but Eos' boxes include a hybrid zinc cathode

Credit: Duke/Eos Energy Storage.

already seen some contenders come and go, a recent report from Navigant Research named 12 'leaders' of this nascent segment. A number of providers including Japan's Sumitomo Electric, UK-based redT and others use vanadium electrolyte pumped through tanks, while others, including US-based Primus Power and Australia's Redflow, use zinc bromine electrolyte. ESS Inc, meanwhile is the only producer of a patented 'all-iron' flow battery.

During discharging, a redox reaction occurs, changing the composition of the electrolyte, which then results in an excess of electrons at the negative electrode. Electrons flow from the negative electrode to the positive, and it's this flow that generates an electrical current. This can then be reversed by applying an electrical current to the electrodes, charging the system. Again, while more expensive than lithium-ion upfront, its durability, ability to cycle heavily without degradation and ability to scale up with the volume of electrolytes in the tank simply representing more energy for longer, mean that providers and technology enthusiasts alike are excited by flow batteries.

Flow batteries essentially offer the chance to decouple power and energy supply, with the power determining the cell size and the energy determined by the amount of the electrolyte in the tanks.

In July 2019, redT achieved pre-qualification status for a 300kWh flow machine into the UK's dynamic firm frequency response market, thought to be the first occurrence of a flow battery providing ancillary services to the grid. It is currently nearing completion of a proposed merger with Avalon Battery, provider of flow batteries to rapidly growing US solar technology provider NEXTracker.

Flow batteries have seen increasing deployment in a number of applications including for remote communities and telecoms sectors, while there are now also a few megawatts of hybrid systems using flow alongside lithium-ion in action. Read this edition's in-depth look at flow batteries by authors from CENELEST, a joint research venture between the Fraunhofer Institute for Chemical Technology and the University of New South Wales (see pages 106-112).

Think zinc

A number of players are working with zinc as a primary material including several start-ups deep into stealth mode. One company already deploying zinc in the form of a zinc hybrid cathode battery is Eos Energy Storage. Founded in 2008, its 'Aurora'-branded zinc cathode battery has a 3-6-hour continuous discharge capability. Mechanically, the technology resembles a flooded lead acid battery, Eos VP for business development Philippe Bouchard says, but "we're plating and re-plating zinc as we charge and discharge the system". Eos also claims the chemistry uses widely available materials, meaning there are no supply chain constraints.

"Because it's an aqueous chemistry and because there's no material degradation of the electrode, this battery can charge and discharge at 100% DOD [depth of discharge] for up to 20 years," Bouchard says, which gives the technology a "big competitive advantage".

Back in October of 2016, Eos raised proceeds of US$23 million through the initial closing of a private placement transaction, at the time saying it planned on using the money to increase deployment of its battery storage product. A year later, the developer had bagged several deployments in various corners of the world, including a 1MWh Aurora system at a wastewater treatment plant in New Jersey, its home state. Also in 2017, utility Engie announced it would install a 1MW/4MWh Eos system in Brazil. Along with a recently brokered UK distribution deal, a 10MW/40MWh project in California – originally announced in 2015 – is still set to go ahead for developer Convergent Energy + Power, although having been awarded by troubled utility PG&E, there may be question marks in the immediate term over that project's timeline. Perhaps most significantly, Eos now has a North America manufacturing joint venture (JV) with nuclear decommissioning equipment maker Holtec, called HI-POWER.


Credit: Lumenion

Lumenion is testing its storage in the grid simulation laboratory of the University of Applied Sciences.

At the starting line

Copper-zinc rechargeable battery

When Alessandro Volta dreamt up the first battery in 1799, copper and zinc were the electrodes. Fast-forward to 2014, when Cumulus Energy Storage developed a patented system for making copper/zinc rechargeable using an ionically permeable separator.

As the battery is charged, the copper electrode releases copper ions into the electrolyte, and zinc ions electro-win onto the zinc electrode. When it's discharged, the reverse then occurs. As long as the zinc and copper ions are prevented from migrating to the opposite electrode the battery can be electrically charged and discharged for thousands of cycles, Cumulus claims. Potential benefits include a lifecycle of 30 years and scalability, as its bipolar design means individual cells can be added in series to meet the desired voltage. It is also 98% recyclable at the end of life.

Copper and zinc are the 25th and 26th most abundant materials in the earth's crust, while the battery technology has an anticipated round trip efficiency of over 80%.

Cumulus' batteries can participate both in the high-energy, long-duration market, as well as ancillary services, due to the chemistry of the battery being aqueous, meaning the response time is "very, very quick", Cumulus CEO Nick Kitchin says.

Cumulus was inspired by the mining industry, from electrorefining – the process of extracting zinc and copper from electrolyte – using plants often operating in the range of hundreds of megawatts.

"What we've done is we've made those processes smaller, we've reduced our development costs and run-time as a consequence of that and we've de-risked the whole process. We've gone in the opposite direction to lithium, which is taking something small and making it big. We're taking something big and making it smaller," Kitchin says.

Cumulus has R&D facilities in California and is developing battery manufacturing in the UK. The company has a Series A funding round currently underway and Series B planned for October 2020. "No one else can do this," Kitchin says, adding that demonstrator systems are currently being put in place, with the company also hoping to announce a large project in Ireland soon.

Liquid metal batteries

Understood to still be at an early stage of commercialisation, start-up Ambri's liquid metal batteries spawned out of the GroupSadoway lab at the Massachusetts Institute of Technology. They comprise a liquid calcium alloy anode, a molten salt electrolyte and a cathode made of solid particles of antimony. This enables the use of low-cost materials and a low number of steps in the cell assembly process, Ambri says.

The active materials in the cells reversibly alloy and de-alloy while charging and discharging. Ambri batteries boast no degradation and are expected to have a 20-year lifetime, with a nominal capacity of 800Ah and nominal continuous power of 160W. The response time comes in at <500 milliseconds, while the cost of the systems comes in at half the cost of lithium-ion when comparing 20-year, eight-hour-duration systems. This is due to the manufacturing of the cells being simpler and the systems not requiring cooling, fire suppression or module- and rack-based BMS equipment unlike lithium ion-systems.

However, the company is yet to put cells into systems. A deal struck this year with NEC makes a commitment to doing that. NEC's Energy Solutions division is expected to make a minimum purchase of 200MWh of cells for systems delivering applications that go to five hours of storage – or more. NEC's Roger Lin also suggested that in addition to good degradation characteristics, the cost of the technology would be "competitive to or just a little bit less expensive than lithium", but that this stage it's "hard to say how it will all [really] end up". However, whilst the cell characteristics and performance of the cells is understood, there are still two years of development ahead for the technology. One of the challenges is Ambri's low voltage in comparison to lithium-ion, with the cells at one volt compared to around four, meaning four times as many Ambri cells are needed compared to lithium-ion to get the same high voltage stack.

Credit: Hydrostor

The A-CAES system is the first grid-scale application of the technology to be approved in South Australia.

Hot, hot heat: Thermal steel at 650°C

Lumenion's thermal energy storage has been deployed as a multi-megawatt demonstration, storing electricity as high-temperature, 650°C heat in steel. It can then either be used as heat or converted back to electricity through the use of a steam turbine. The storage can continuously supply thermal energy with temperatures of 80-550°C for around 48 hours, with a charging pattern of eight hours out of 48. The charging to discharging ratio can be 1-5 or 3-5 depending on the application of the storage, and Lumenion claims it has an efficiency of 95% using the principle of combined heat and power (CHP).

In October 2018, the company announced it was partnering Swedish utility Vattenfall and municipal housing company Gewobag for a 2.4MWh thermal energy storage system in Berlin, Germany.

It's recommended by Lumenion as the answer to large-scale, bulk storage and as a complement to faster-responding assets such as batteries. The system will absorb power generated by local renewables plants, wind and solar, stored at a claimed cost of less than €0.02 per kWh. The technology relies on no rare earth minerals and as company CEO Alexander Voigt points out, there are already plenty of 'gigafactories' producing steel around the world. One to watch.

Liquid air & advanced compressed air (LAES, A-CAES)

UK-headquartered Highview Power announced a 50MW/250MWh 'cryobattery' project in October 2019, a technology kicked off in 2005 by researchers at the University of Leeds in England. The company's first pilot plant was operational between 2011 and 2014.

Cryobatteries cool ambient air to below -270°F (-170°C), causing a 700-fold contraction in its volume from gas to liquid. This liquid air is then stored in conventional insulated tanks at low pressure and when energy is required, the air is warmed again and pumped to pressure.

It is then expanded back to gas, this time increasing in volume 700 times over, through a standard expansion turbine connected to a generator.

The system's expected lifespan of 30+ years is one of its key benefits, with the system also having no geographical constraints on where it can be deployed. Highview claims it as the lowest-cost locatable technology at utility scale.

The technology can be built from 10MW to 200MW+ power output, with a storage capacity of 40MWh to over 20000MWh+, it claims.

Highview has signed a deal with EPC partner TSK for marketing its systems into Spain, the Middle East and South Africa. Currently, only two of the systems have been deployed, although there are plans for five 250MWh systems at as-yet unrevealed locations in the UK.

Another company to be utilising air – though in a different fashion – is Hydrostor. Hydrostor claims its A-CAES plants are the lowest installed cost per kWh for large-scale, long duration energy storage. It has a 30+ system life, with unlimited cycling and no replacement required, according to the company.

The technology uses off-peak or surplus electricity from the grid, or from a renewable source, to run a compressor, which produces heated compressed air. Heat is then extracted from the air stream and stored inside a proprietary thermal store.

Air is stored inside a purpose-built underground cavity, where hydrostatic compensation keeps the system at a constant pressure. Hydrostatic pressure forces the air to the surface, where it is re-heated by the thermal store and expanded through a turbine, which generates electricity. Hydrostor says that this re-use of thermal energy is what makes so-called adiabatic advanced compressed air energy storage (A-CAES) so efficient.

It is ideally situated for use in behind-the-meter or remote applications for mines and large industrial operations, Hydrostor says, with a duration of between four and 24+ hours.

In July, Hydrostor secured approval to build the first grid scale application of the technology in Australia. The system comes in at 5MW/10MWh, with the location a former zinc mine near Strathalbyn, South Australia.

Hydrostor also completed work on a multi-megawatt, commercial system in Canada in November. The project had been under joint development with NRStor since 2017 and is 1.75MW peak power output rating. It has a 2.2MW charge rating, with a 10MWh+ of storage capacity.


Credit: Energy Vault/Business Wire

Inspired by pumped hydro, weights are raised and lowered from the storage tower.

It's all in the gravity

Using gravity to store energy boils down to releasing a weight and converting the kinetic energy of the fall into electricity. There are a handful of providers in this area. However, the technology proposed by one start-up implies a surprising level of complexity.

Swiss start-up Energy Vault was inspired by pumped hydro power stations to create its gravity-based energy storage solution.

Concrete blocks weighing 35 metric tonnes are lowered up and down an energy storage tower, storing and releasing energy as they go. As the bricks are lifted, energy is stored in the elevation gain. As they are returned to the ground, the kinetic energy generation from the falling brick is converted into electricity.

The system uses control software to make sure the bricks are placed in the right location through which Energy Vault touts "very fast response times".

It claims a lifespan of 30+ years with zero degradation and 90% round trip efficiency. The storage can deploy 4-8MW of continuous power for 8-16 hours.

Energy Vault received a US$100 billion boost in the form of an investment from SoftBank Vision Fund in August 2019. It is deploying its first 35MWh tower in northern Italy and has an agreement to build another for India's Tata Power Company.

The verdict

Speaking on a panel at this year's Solar & Storage Live event in the UK, NGK's business development head Gauthier Dupont said that NAS batteries and other promising – or even proven – long duration technologies may not currently get the headlines, but if they are to compete, they certainly need to start getting the investment that lithium-ion, the 'sexier' technology, attracts. For many technologies it will be a question of access to manufacturing facilities of appropriate size that will drive scale and therefore cost reductions. For others, it's a question of getting proven through successful deployment beyond the pilot phase and for others still, it remains a matter of technology development. And while they can't all be the 'cheapest' as they claim, there's probably room for diverse long duration technologies in tomorrow's world. One thing is for sure, the race is on, and the window to deliver is getting shorter, even if the hours of energy stored and discharged are going to get longer. ■

Taking charge: Energy Storage Association CEO Kelly Speakes-Backman

Policy | Despite making huge strides forward, the energy storage industry's work in helping stakeholders across the value chain understand the technologies and the roles they can play in a renewable energy future is far from done. Andy Colthorpe speaks with Energy Storage Association chief executive, Kelly Speakes-Backman, at the forefront of the industry's push into unchartered regulatory, policy and public affairs matters

"We almost doubled last year, we're on track to double here again in 2019 and projections show that we are looking to triple in 2020," Kelly Speakes-Backman, US Energy Storage Association (ESA) CEO, says.

"That's the state of where we are," the trade group chief adds, explaining that ESA represents all forms of energy storage, "not just lithium-ion". Her home country's energy storage industry is enjoying a rare degree of what she calls "extremely strong, bipartisan support," from Congress and the Department of Energy to other administrations including the Department of Commerce.

'An efficient, affordable and sustainable grid'

This support comes because there's a growing recognition, Speakes-Backman says, that energy storage – batteries or otherwise – is a help, not a hindrance to the grid.

"Energy storage is certainly there to integrate intermittent resources like solar and wind and help enable our grid to get cleaner, but it's also there for grid operators to improve the efficiency of the grid, to improve resilience.

"We are there for an efficient, affordable and sustainable grid. It's all of those things. That's part of the reason why we're enjoying such strong support. It's being embodied through tremendous growth."

Now based in Washington DC, Maryland native Speakes-Backman became CEO at the ESA in mid-2017, representing its 180 member organisations along the value chain from electric utilities to financiers, manufacturers and component suppliers at events and in the corridors of power.

Fast-moving tech vs incumbent frameworks

A former Maryland Public Service Commissioner in the early 2010s, Speakes-Backman understands the pressures that those coordinating electricity networks face. She says that educating stakeholders remains a crucial part of ESA's work.

"By that ('stakeholders') I mean decision makers like big commissioners, federal commissioners, independent system operators, utilities who are part of our membership, helping people understand what storage is, and what it isn't.

"As much as we're an enabling technology, we're disruptive to the regulatory frameworks that exist both at the federal level and at the state level. We're not necessarily generation, not necessarily transmission, we're not really distribution but we can be all of those things in a single asset and that's different than what typically been considered in long-term planning. So it is disruptive."

However, while disruptive to the existing energy paradigm, energy storage is also hugely enabling, Speakes-Backman emphasises. Not only for solar and wind, but natural gas plants can be made faster-ramping, more efficient and able to play into ancillary services markets with the addition of energy storage, for example.

"And it helps nuclear and even coal and other resources react faster to demand changes on the grid, so to me, it's an enabling technology but [it's] disruptive to frameworks," Speakes-Backman says.

US$1bn investment mark, rapid jobs growth

Energy and climate have become politicised topics on both sides of the Atlantic, but so too has employment. Coal plants are retiring and no one whose relative died of black lung will miss them, while it has been reported that some workers at the UK's Hinckley Point nuclear construction site are suffering mental health problems, facing years away from their homes and families.

Solar has been a mostly bright story in terms of rising employment and – at the moment at least – energy storage is also a job creator. This year, investments in US energy storage hit the US$1 billion mark and the rise in the number of people the sector is hiring is worthy of comment.

"For the first time there was a breakout on energy storage for the grid in the jobs report for energy which used to be done by the DoE but is now done by Energy Futures Initiative with [former US Energy Secretary] Ernie Moniz and some of his team.

"Energy storage had the greatest growth in jobs of any sector in

A recent storage project in Jacksonville, Florida. Even the non-typical storage states are recognising the technology's value, says Kelly Speakes-Backman

Credit: Sungrow

the US; by 18%, the number of people employed increased in 2018. So, along with doubling our market, we're also showing strong growth in jobs. Now, in absolute values, it's not as big as solar or wind, those jobs are big numbers and they dwarf coal right now, but storage is coming along."

The price is right

The need for education about renewable energy and low emissions technology shows no sign of dying down. In terms of that education piece, one 'myth' that's often encountered is that "batteries are too expensive for the grid". Which perhaps comes from fundamental misunderstanding of the roles batteries can play, but is nonetheless worth addressing. Speakes-Backman is more than happy to do so:

"I have to always add that we represent thermal, mechanical, pumped hydro, all forms of storage. But specific to batteries and lithium-ion batteries, the costs have dropped down 50% in the last three or four years overall. In the C&I market, those lithium-ion batteries, installation costs have dropped 80% in the last three years. So it is a big barrier that we have, to help people understand that you have to have up-to-date pricing," Speakes-Backman says.

> "We are seeing a transition for utilities to consider storage in their long-term planning, which is really terrific"

Customers also have to understand what it is they're buying, she adds: "This is not like a traditional asset, where prices, installed costs, bounce up and down maybe within a window of 5% to 10%. Costs are going down and projected to continue going down 10% to 15% year-over-year, and that's in some of the learnings of soft costs and installation costs right now."

As people are no doubt starting to see, EVs and consumer electronics battery volumes are driving costs down and "driving economies of scale for the grid-sized or stationary storage market that are incredible", the ESA CEO says.

"When we see Commissions looking at the cost-effectiveness of storage, one of the first things we say is 'make sure you've got up-to-date pricing'."

And it isn't just what batteries and systems costs that are often misunderstood, there's also the so-called 'value side' of energy storage. Moves to smarter, better metered electricity networks and markets, with settlement timeframes that have shorter windows, are a natural fit for the multiple services energy storage can provide, both today and in the future."

Long-term resource planning

Key to energy storage gaining a mainstream foothold in the US has been way (some) utilities have welcomed batteries. Moving forward, utilities will increasingly put energy storage in their long-term plans.

"We are seeing a transition for utilities to consider storage in their long-term planning, which is really terrific," Speakes-Backman says.

"We've done a lot of work to make sure that utilities are included in our membership, so they can understand from the inside what some of their competitors and suppliers are thinking in terms of energy storage and the value it brings.

"We've also got independent power producers (IPPs), who often service utilities and sometimes compete with them, so we've brought them into our membership as full voices. We've also done quite a bit of work in white papers on how utilities can use storage in their long-term planning. Because we are fiercely defensive of competition in its purest form, that means we don't believe utilities should be cut out of ownership - but it should be a fair playing field."

Wonky talk

In the previous issue of PV Tech Power we heard from lawyer Jennifer Key that there could be some pushback in the US over FERC Order 841, the Federal Energy Regulatory Commission's instruction that transmission and distribution operators allow energy storage – including behind-the-meter – to play into wholesale markets.

On the contrary, Kelly Speakes-Backman says that as a former regulator and keen policy wonk herself, she has not heard of any such pushback. Along with campaigning for a Federal Investment Tax Credit (ITC) for standalone storage ("no other policy would be more impactful"), the ESA looks ahead to Order 841's implementation.

"[In addition to the ITC and Order 841], there's also a bill that recently passed through Senate… it had broad support," she says. "That bill, Senate Bill 1602 is pretty exciting for us on the federal level as it puts about US$1.4 billion to the DoE in a number of different ways. One is R&D, especially for long-term storage support, the other is for demonstration projects, supporting the efforts of municipal utilities and co-ops."

Keep an eye out too, Speakes-Backman says, for increased energy storage activity across many more than the often-talked about leading states in the US: "Besides the [leading] states of Massachusetts, New York and California and Hawaii that are all moving forwards full speed with energy storage, there have been a number of states that have either put RPSs in place and are now looking at how storage can support those goals, then states like New Jersey and Minnesota, Michigan and Maryland – states that don't get the headlines of these really large states, they're moving forward.

"Maryland, my home state, they're undergoing a pilot, which is only about 10MW, but it's a pilot to test not the technology, but ownership models. And that's really exciting." ■

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