PV POWER TECH

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SOLAR'S 2030 BLUEPRINT

Entering a crucial decade, what direction is PV technology, scale, O&M and grid relationship taking? p.15

SYSTEM INTEGRATION

How AI is helping integrate more solar in Australia, p.43

PLANT PERFORMANCE

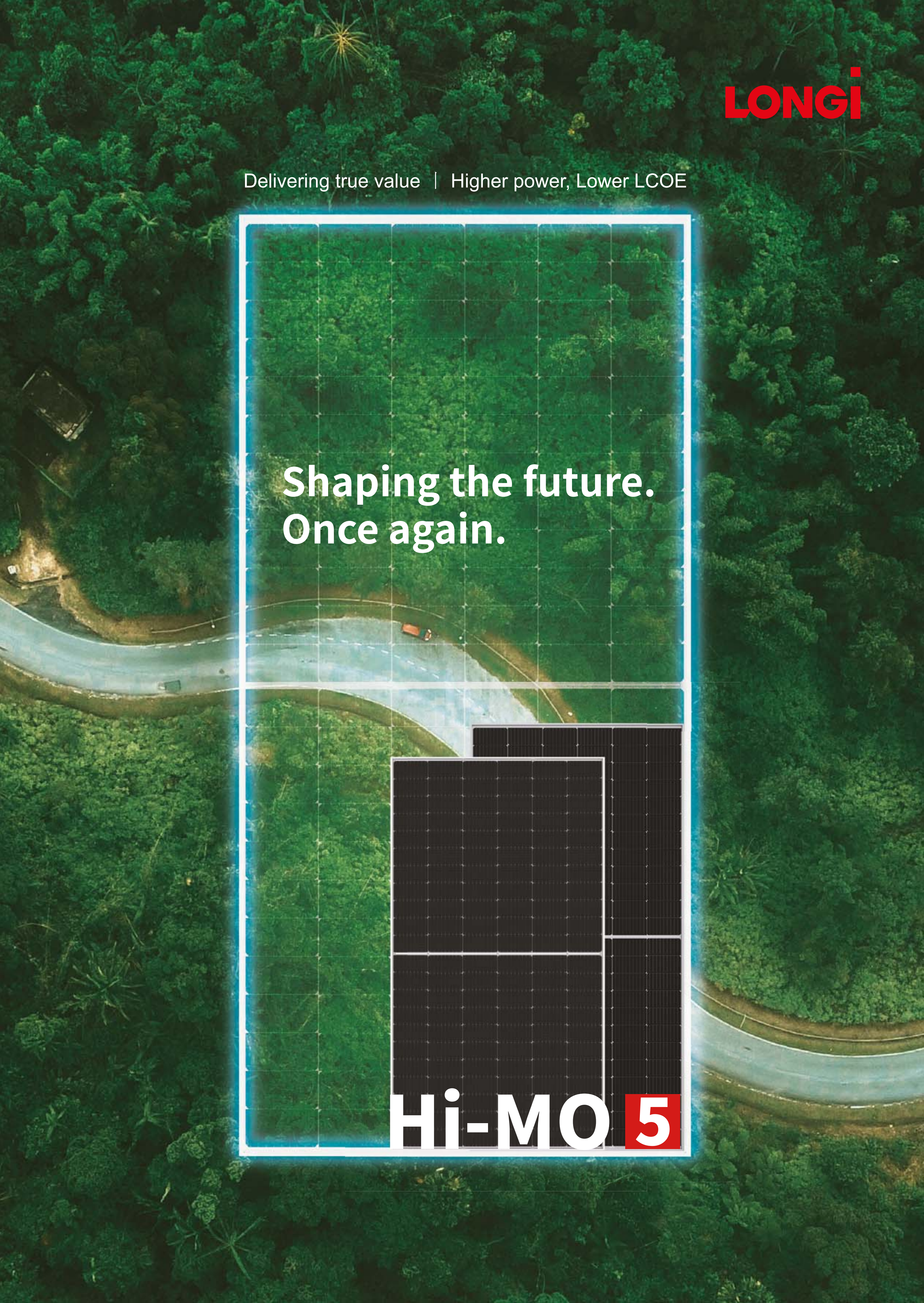
Providing O&M in desert climates, p.51

FINANCIAL, LEGAL, PROFESSIONAL

How has extreme weather reshaped asset insurance? p.66

STORAGE & SMART POWER

Everything you need to know about fire safety, p.75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Brands of Solar Media:

Cover illustration by Adrian Cartwright, Planet illustration

Introduction

Welcome to volume 29 of PV Tech Power, published just weeks after what is hoped will be a landmark moment for the world.

While there are rightful protestations about the ambition, or lack thereof, demonstrated at the COP26 climate summit in Glasgow, Scotland, in November, the Glasgow Climate Pact keeps the 1.5 degrees Celsius target alive. It also places even more importance on action this decade, leading us to contend with what solar PV will need to achieve before 2030.

While it is, of course, nigh on impossible to predict with any great confidence what solar PV will look like just over eight years from now, the industry is hurtling along a certain trajectory. We've unpicked trends across technology and manufacturing and assessed future routes to market and grid relationships in our cover story (p.15) to form something of a blueprint for solar's decade of action.

Truthfully, however, there is already much tangible progress for the industry to reflect upon this decade. We've seen how artificial intelligence principles are being used in Australia to accommodate more solar and other renewables into national grids (p.44), a plethora of new approaches to the renewables-grid relationship beginning to form (p.47) and a continued evolution of the understanding pertaining to O&M, resulting in far more comprehensive offerings in this space (p.51).

While opportunities continue to open up and be taken advantage of in the solar sphere, there are new challenges to consider. It's perhaps one of the greatest ironies for renewables that the very crisis they're established to tackle – climate change and the increasing incidence of extreme weather events – also poses a significant threat. High winds, soaring heat and destructive hail storms threaten the operating nature of solar farms and as you can read in our Financial, Legal Professional section (p.66), it's changed how asset insurers consider renewable energy projects.

But the renewables sector is nothing if not resilient. Our Storage & Smart Power section contains three specific articles that document how the sector is tackling persistent challenges in fire safety, ensuring a just energy transition and managing battery assets.

So while the Glasgow Climate Pact may not be perfect, or even anything other than, as Greta Thunberg puts it, "blah, blah, blah", the industries we work in remain supremely adept at rising to the challenge and going above and beyond in the pursuit of a clean energy economy.

Thank you for reading, and we hope you enjoy the journal.

Liam Stoker
Editor in chief
Solar Media

Contents

08-14 NEWS
Round-up of the biggest stories in PV from around the world.

15-32 COVER STORY
16 **The solar decade**
Uncovering the PV industry's growth blueprint out to 2030

18-20 **The race to the TOPCon**
What are the prospects for n-type technologies in solar's quest for efficiency gains?

21-24 **Scaling up to the challenge**
How solar will move from gigawatts to terawatts, both in manufacturing and deployment

25-26 **The grid in 2030: examining the changes needed**
Solar's relationship with the grid must improve, but how so?

28-29 **Charting new routes**
Subsidies are consigned to the history books, and in their place corporate PPAs and merchant revenue streams

30-32 **An automated and intelligent future for O&M**
Autonomous drones, AI-led degradation prevention and robotic security

34-42 MARKET WATCH
34-36 **What does it take to build (and maintain) solar in MENA's harsher climes?**
Molly Lempriere takes a look at the causes for optimism for solar in the desert

38-42 **Is the Glasgow Climate Pact a boon for solar, or a COP out?**
Sean Rai-Roche reflects on the outcomes of COP26 and asks what's in it for solar

44-50 SYSTEM INTEGRATION
44-46 **How AI can help grids accommodate more solar PV**
By Dr. Christoph Bergmeir, Monash University

47-50 **What transmission technologies are easing grid connection?**
Three case studies of cutting-edge grid technology

Building a Fully Connected, Intelligent World

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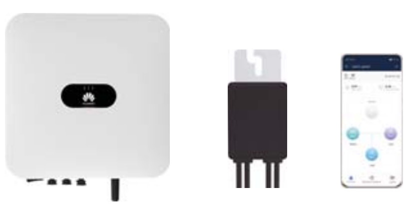

HUAWEI

51-60 PLANT PERFORMANCE

51-56 **Climate-specific O&M for PV power plants**
By Ulrike Jahn, VDE Renewables and Dr. Bert Herteleer, KU Leuven

58-60 **The right time for repowering?**
Alice Grundy explores the nature of solar asset repowering

62-64 DESIGN & BUILD

62-64 **Project briefing:** How customised install techniques helped install Singapore's largest floating solar project
Jules Scully learns the inside story of the development of the 60MWp Tengeh floating solar farm in Singapore

66-69 FINANCIAL, LEGAL, PROFESSIONAL

66-69 **The role of insurance and risk management in solar power project financing**
By Duncan Gordon, Gallagher

71-89 STORAGE & SMART POWER

75-76 **Stopping thermal runaway six minutes before it starts**
By Steve Kenny, Honeywell Building Technologies

78-79 **Battery storage fire safety is everyone's business**
Energy Safety Response Group's Paul Rogers talks to Andy Colthorpe about the pressing matters of fire safety

80-83 **Neighbourhood batteries in Australia**
By experts from the Australian National University

84-89 **How to design a BMS, the brain of a battery storage system**
By Christoph Birkl, Damien Frost and Adrien Bizeray of Brill Power

REGULARS

03 **Introduction**

43 **Products**

90 **Advertisers index**


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EUROPE

Solar auctions

Turkey to support 1.5GW of solar PV in latest tender

Turkey will aim to procure power from 76 solar projects with a combined capacity of 1.5GW through an upcoming tender. Representing the fifth round of the country's YEKA large-scale renewable energy programme, the YEKA GES-5 tender is for projects with capacities of 10MW, 20MW and 30MW. The country's Ministry of Energy and Natural Resources has set an initial ceiling price of TRY 0.40/kWh (US$0.045/kWh) for the tender, with interested participants required to submit bids on 12 January 2022. The announcement was made less than three months after the ministry revealed plans for the fourth YEKA round, which will tender 1GW of solar and require bids to be sent on 30 March 2022.

Credit: Kalyon PV

Turkey is aiming to have 15GW of installed solar by 2027.

Spain awards just 866MW of solar in renewables auction as prices jump

Average winning solar bids in Spain's most recent renewables auction came in above those for wind as interest among PV bidders faltered against a backdrop of rising equipment costs and regulatory challenges. The 3.3GW auction closed with 866MW of capacity going to solar bidders, with the lowest winning solar bid of €0.0244/kWh (US$0.0284/kWh) 64% higher than the lowest PV price in Spain's renewables auction in January. Spanish utility Naturgy secured the most solar capacity in the latest auction, winning 221MW, followed by Nearco Renovables (216MW) and Ignis (144MW). While 600MW of solar and wind capacity was reserved for plants that must be operational by the end of September 2022 as part of government efforts to rapidly support new renewables as a solution to soaring electricity prices, this segment only allocated 22MW.

Greece

RWE and PPC form joint venture to develop 2GW of solar in Greece

German energy major RWE has established a joint venture with Greek utility PPC that will develop utility-scale solar projects in Greece with a total capacity of up to 2GW. With RWE Renewables holding a 51% interest in the venture and PPC Renewables 49%, the collaboration could be extended further in the future, the companies said. They touted the complementary strengths of the tie-up, which will combine RWE Renewables' track record in financing, construction and operating projects with PPC Renewables' knowledge of the Greek market and relationships with key stakeholders.

People news

RES names ex-Vestas, SunPower exec as new CEO

Renewables developer and asset manager RES has appointed Eduardo Medina as its new chief executive, with the former Vestas, SunPower and Acciona exec taking over in November. Medina's previous role was as North America president for wind developer Vestas, having previously held senior positions at solar installer and former module manufacturer SunPower, developer Acciona Energia and power electronics businesses General Electric and Gamesa. He said his focus going forward would be on bolstering RES' project development and support services functions. Medina replaced Ivor Catto, who has retired after leading the company for 13 years. In a separate announcement from RES in September, the company said it secured planning permission for the largest floating solar project authorised in France to date, a 65.5MW plant that will be installed at a former quarry in the northeast of the country.

PPA

Google taps Engie for 24/7 power supply backed by German renewables

French utility Engie has signed a 24/7 power supply agreement with Google for 140MW of carbon-free energy in an arrangement the companies have called a "first-of-its-kind". Under the three-year agreement, Engie will construct a portfolio of solar and wind to supply Google with enough round-the-clock energy to ensure that 80% of its German operations are carbon free by 2022. Google is aiming for all its campuses and data centres worldwide to be carbon free by 2030. Through Engie, Google will purchase electricity from 23 renewable energy projects across five German states. The projects will either be new plants or existing assets that will see their life extended.

Financing

Galp bags EIB loans to finance 2.1GWp of solar in Spain and Portugal

Oil and gas company Galp has secured loans from the European Investment Bank (EIB) to support the construction of more than 2.1GWp of solar projects across Spain and Portugal. The largest agreement consists of an EIB green energy loan of up to €325 million (US$378 million) to finance the construction of around 2GWp of utility-scale PV plants in Spain that are expected to break ground in the next three years. These installations will have capacities ranging from 24MWp to 449MW. The EIB, which is the European Union's lending arm, said the portfolio could be supported by a further €325 million that could be signed in a project finance format at a later stage. Alongside this, the EIB will provide a €40 million green energy loan for Galp to build and operate four interconnected solar plants with a total capacity of 144MWp in the south of Portugal.

AMERICAS

Section 201 bifacial exemption reinstated by international trade court

An exemption for bifacial solar panels from Section 201 tariffs in the US has been reinstated after a decision passed down by the US Court of International Trade (CIT). The judgement means that bifacial solar modules can now be imported to the US free of punitive tariffs under the Trump administration's Section 201 trade regime. Furthermore, an increase of the Section 201 tariff rate from 15% to 18% was rescinded by the CIT. Refunds will be paid to parties to have paid any resultant tariffs. The development, considered a surprise, has been celebrated by the US solar sector. Abigail Ross Hopper, president and CEO at the Solar Energy Industries Association (SEIA), said the decision was "clearly the right conclusion".

Updated FAQs on the US' Withhold Release Order

The US has published additional details about a withhold release order (WRO) on silica-based imports linked to Hoshine Silicon Industry. Customs and Border Protection (CBP) said polysilicon products sourced from China's Xinjiang region "carry a high risk of forced labour", adding that an importer "can lower its risk of exclusions under the Hoshine WRO if it sources polysilicon from outside of Xinjiang". The CBP provided guidance for importers on how to exercise reasonable care with regards to the order and included more flexible language concerning documentation that may be requested.

Trade tariffs

US Department of Commerce rejects AD/CVD petition, price normalisation expected

The US Department of Commerce rejected a petition calling for an extension of anti-dumping and countervailing duties (AD/CVD) across Southeast Asia, citing the ongoing anonymity of the petitioners. Prices for solar modules in the US are expected to normalise following the rejection but the stabilisation of prices is expected to take some time, with the "ripple effect" of the petition still affecting solar manufacturing. Confirmation that modules can now flow from Southeast Asia to the US was celebrated by developers and allows the solar industry to collaborate on other issues affecting module supply to the US. Opponents of the petition said it threatened to "devastate" the US solar industry and put 18GW of projects at risk of collapse. Petitioners American Solar Manufacturers Against Chinese Circumvention (A-SMACC), whose anonymity has proven contentious, have stressed they could yet re-file and that the group "strongly disagrees" with the decision.

Credit: Port of California

The petition alleged Chinese solar manufacturers have circumvented anti-dumping tariffs through Southeast Asian subsidiaries

US stimulus packages

Congress passes infrastructure bill, all eyes on budget reconciliation package

The US House of Representatives passed a US$1 trillion bipartisan infrastructure deal that will see the country's power infrastructure modernised to support new renewables projects. Following a months-long standoff between Democrats, the legislation passed 228-206 on 4 November. It includes the largest investment in clean energy transmission and the grid in American history, according to the White House. It will also fund new programmes to support the development and deployment of "cutting-edge clean energy technologies" to accelerate the US' transition to a zero-emission economy. Following this, all eyes are firmly on the US$1.75 trillion Budget Reconciliation Bill currently trying to pass through Congress. The package includes nearly US$570 billion for tax credits for utility-scale and residential clean energy – including solar PV – as well as incentives to spur domestic PV manufacturing.

Asset performance

Underperforming US solar assets prompt P50 estimate concerns

The performance of US solar assets against P50 estimates worsened over the last decade, prompting calls for the use of real-world data-driven benchmarks when financing new projects. A report by Solar asset insurer kWh Analytics's showed that while power production modelling tools are becoming more sophisticated, there is still a level of subjectivity in how P50 estimates are produced, preventing them from stacking up against real-world data. It concluded that P50 estimates continue to be highly variable and with the gap between those estimates and actual generation only widening.

Colombia

Colombia awards 800MW of solar in third renewables auction

Colombia has awarded contracts to 11 solar PV projects with a combined capacity of 796.3MW in its third renewable energy auction. The winning projects are backed by 15-year power purchase agreements (PPAs) and are required to be operational from January 2023. Average winning bids in the auction yesterday (26 October) were COP155.8/kWh (US$0.0414/kWh), according to Colombia's Ministry of Mines and Energy, which said the 11 PV plants will support 4,800 jobs across the country. "The success of this new auction shows that the energy transition in Colombia is a reality," said Minister of Mines and Energy Diego Mesa. Around 1,365MW of solar and wind projects that were awarded contracts in a 2019 auction are now said to be under construction across Colombia.

MIDDLE EAST & AFRICA

Green hydrogen

Plans revealed for 10GW green hydrogen project in Mauritania

Oil and gas company Chariot has signed a memorandum of understanding with the government of Mauritania to progress with a solar- and wind-powered green hydrogen complex in the country. The 10GW Project Nour facility has been given exclusiv-

Government-backed renewables

Abu Dhabi targets 8.8GW of renewables by 2025 in COP26 pledge

Abu Dhabi has said it will bring its renewables capacity up to 8.8GW by 2025 as it seeks to reduce emissions associated with power generation by 50% over the next decade. The capital of the United Arab Emirates hopes to increase the share of renewables in its energy mix to 31% by 2025 from 13% today. It predicts that around 7% of its electricity mix at that time will come from solar, with 47% from nuclear and the rest from fossil fuels. Its Department of Energy (DOE) announced the initiative at COP26 in Glasgow and outlined its plan that hinges on the continued roll out of solar and other renewables, the electrification of water production and supporting energy efficiency measures. Awaidha Al Marar, chairman of the DOE, said that the commitment was "underpinned by a strategic shift to low-carbon technologies with large-scale investment in solar and nuclear energy to drive down emissions" and lauded the city's track record when it came to sustainability.

Credit: Masdar

A solar PV plant located in Abu Dhabi which has been developed by Masdar

ity over an onshore and offshore area totalling around 14,400 square kilometres in the northwest African country. Chariot is now starting work at the site to assess solar and wind resources and the environmental and macroeconomic impact of the installation. The company is intending to form a consortium to bring forward the project. Benefiting from Mauritania's world-class solar and wind resources, Project Nour has the potential to allow Mauritania "to become one of the world's main producers and exporters of green hydrogen", Chariot said.

Projects

Moroccan solar-wind mega hybrid unveiled

A 10.5GW solar-plus-wind project is under development in Morocco's Guelmim Oued Noun region, with 3.6GW of this to be exported to Great Britain. Xlinks – the company behind the Morocco-UK Power Project – said the project is capable of generating for an average of 20+ hours a day, taking advantage of the high solar irradiance in the south of Morocco alongside consistent convection desert winds to provide an alternative source of zero carbon electricity to GB. It is also to feature a 5GW/20GWh battery facility, helping to ensure the power generated can be delivered every day, resulting in a dedicated, near-constant source of flexible and predictable renewable energy. The project is currently making progress in gaining the requisite regulatory and government approvals in Morocco, according to Xlinks.

TotalEnergies agrees to build second 1GW solar plant in Iraq

French energy major TotalEnergies has agreed to build a 1GW solar farm in the Basra region of southern Iraq in a deal that also sees substantial investments in new gas networks and seawater treatment totalling US$10 billion. It is Total's second GW-scale project in the country after signing an agreement with Iraq's Ministry of Oil in March to install 1GW of solar PV across Iraq's central and southern regions. However, as part of the investment, Total is also constructing a new gas gathering network as well as a large-scale seawater treatment unit. "This is the biggest investment by a western company in Iraq," said Ihsan Abdul Jaber, Iraq's oil minister according to French media reports. It comes as the country attempts to increase its power generation capacity following a series of electricity shortages.

Off-grid solar

Invest in off-grid solar to unlock economic growth in Sub-Saharan Africa, says new report

Access to off-grid electricity should be seen as a key mechanism to drive rural development and improve economic wellbeing and living standards in Sub-Saharan Africa (SSA), according to a new report by University College London's Engineering for International Development Centre and off-grid, pay-as-you go solar company BBOXX. Entitled Off-Grid Energy and Economic Prosperity, the report highlights the need for governments and policymakers to prioritise off-grid solar as a means to sustainable economic development. Currently, more than 550 million people in SSA live without access to electricity, with the region having an electrification rate of just 47%, the lowest in the world. The pandemic has not only hamstrung efforts to improve on this figure but has also damaged regional economies' growth rates. Moving forward, off-grid electrification plays a vital role in extending electricity access to rural communities, improving economic resilience and recovering from the pandemic, said the report.

ASIA-PACIFIC

China

China submits 'disappointing' NDC to the UN that commits to 1.2TW of renewables by 2030

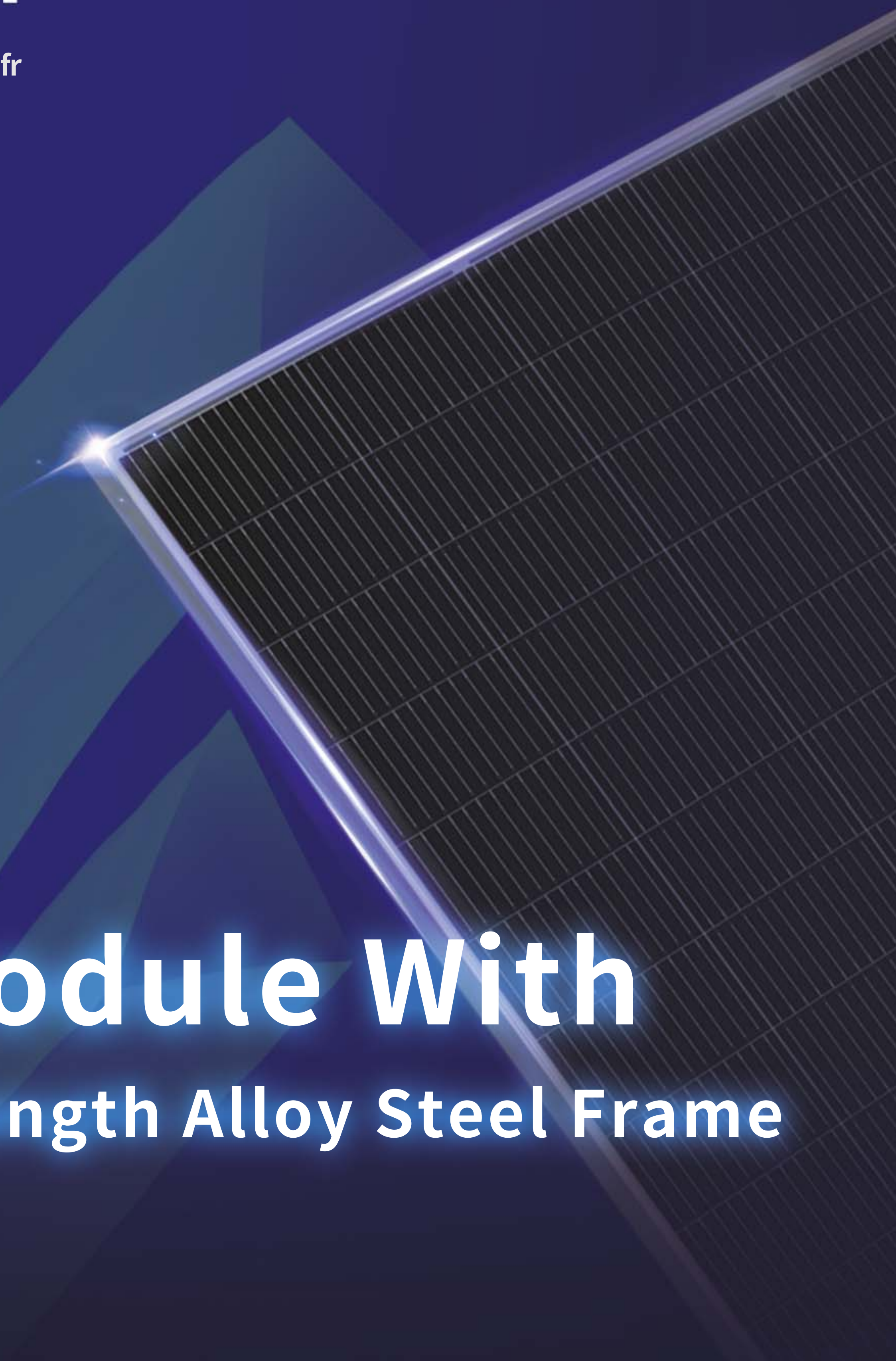
China submitted its highly anticipated and long awaited nationally determined contribution (NDC) to the United Nations at the end of October, committing to a renewable energy capacity of 1.2TW by 2030. However, the plan has been condemned by climate organisations that say it represents little ambition or progress from its last NDC in 2016.

China installs 12.55GW of solar in Q3 2021 as distributed PV leads the way

China installed 25.56GW of new solar installations in the first nine months of 2021, with distributed installations accounting for nearly two-thirds (64.2%) of installs in the year to date. Figures published by China's National Energy Administration (NEA) in October revealed that of the 25.56GW of solar installed in Q1 – Q3 2021, around 9.15GW was centralised utility-scale solar PV while 16.4GW was distributed solar.

risen

Tier-1 Solar PV Module Mfr



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China

China sets initial 2022 solar subsidy pot at US$357.2m

China has revealed its initial subsidy limits for existing renewables projects in 2022, however it remains to be seen whether the funding is to be topped up. In November 2021, China's Ministry of Finance set out its first tranche of funding for existing renewable projects for the forthcoming year, making RMB3.87 billion (US$607.3 million) available. Of that total, RMB2.28 billion (US$357.2 million) has been set aside for solar PV projects, which is a marked decrease – down 32.6% – on the RMB3.384 billion made available for projects in 2021.

Credit: Beijing Energy International Holdings

China signals construction start of 100GW, first phase of desert renewables rollout

China has started building work on the first 100GW phase of a solar and wind buildout that is likely to see hundreds of gigawatts deployed in the country's desert regions. While the location and construction timeline of the projects, nor the total expected capacity or the number of subsequent phases, have not been revealed, the scheme will represent a notable chunk of China's ambition of reaching more than 1,200GW of installed solar and wind capacity by 2030.

Japan

Japan's policymakers approve higher 2030 renewable energy target

The Cabinet of Japan's government has approved a plan to raise the national target for renewable energy in the electricity generation mix to between 36% and 38% by 2030. In October, the Cabinet gave its official approval to the 6th Strategic Energy Plan, which was presented in its draft form in late July, after the government Advisory Committee for Natural Resources and Energy began deliberations in October 2020.

Eneos to buy Japan Renewable Energy in deal worth US$1.8bn

Japanese oil and metals giant Eneos has bought Japan Renewable Energy Corporation (JRE) as it seeks to bolster its sustainable portfolio and target renewables growth. The transaction is expected to be completed in late 2022, when JRE will become a wholly-owned subsidiary of Eneos. The deal is worth US$1.8 billion, according to the Nikkei.

Indonesia

Sunseap planning 7GWp of solar in Indonesia, eyes link to Singapore via subsea cable

A consortium led by Sunseap Group has signed a memorandum of understanding to develop 7GWp of PV projects at an Indonesian archipelago that will transmit energy to Singapore via a proposed subsea cable. Coupled with multiple energy storage systems totalling more than 12GWh, the development will be one of the largest cross-border interconnected clean energy projects in Southeast Asia.

Indonesia to install 4.7GW of solar by 2030 under decarbonisation plan

Indonesia is aiming to deploy an additional 4,680MW of solar by 2030 as part of efforts to reach net zero carbon emissions by 2060. Energy minister Arifin Tasrif said a new 2021-2030 master plan will see Indonesia source 51.6% of its added power capacity by the end of the decade from renewables, while the remainder will be new fossil fuel plants.

Projects

Azure Power lands 150MW hybrid project as part of 1.2GW SECI programme

Azure Power has received a letter of award for its first 150MW interstate transmission system connected solar-wind hybrid project with the Solar Energy Corporation of India (SECI). The project will require the deployment of 100MW of solar and 50MW of wind capacity within 18 months of signing the power purchase agreement (PPA). The contract is to run for 25 years at a fixed tariff rate of INR2.35/kWh (US$0.032c/kWh) and forms part of the 1.2GW ISTS 'Hybrid Tranche – IV' tender from SECI.

Uzbekistan planning two tenders for 400MW of solar

Uzbekistan is set to announce two new tenders for 400MW of solar capacity by the end of 2021, the Central Asian nation's energy minister, Alisher Sultanov, has said. Speaking at the third Uzbek-German business forum, held in Frankfurt, Sultanov invited German companies to participate in the tenders and revealed that further tenders to provide 200MW of energy will be announced in 2022.

Nexif Energy signs power supply deal for 75MWp project in the Philippines

Independent power producer Nexif Energy has secured a ten-year power supply agreement (PSA) for a 75MWp solar plant to be constructed in the Philippines. The deal will see SN Aboitiz Power (SNAP), a joint venture between Philippine utility Aboitiz Power and renewables developer Scatec, purchase most of the electricity and green certificates generated by Nexif's Calabanga solar farm in the Camarines Sur province.

MANUFACTURING

India

India confirms major expansion of PV manufacturing PLI support scheme

India's government is set to scale up funding for its production-linked incentive (PLI) programme for solar manufacturing as it eyes exports of PV equipment. While the scheme was originally

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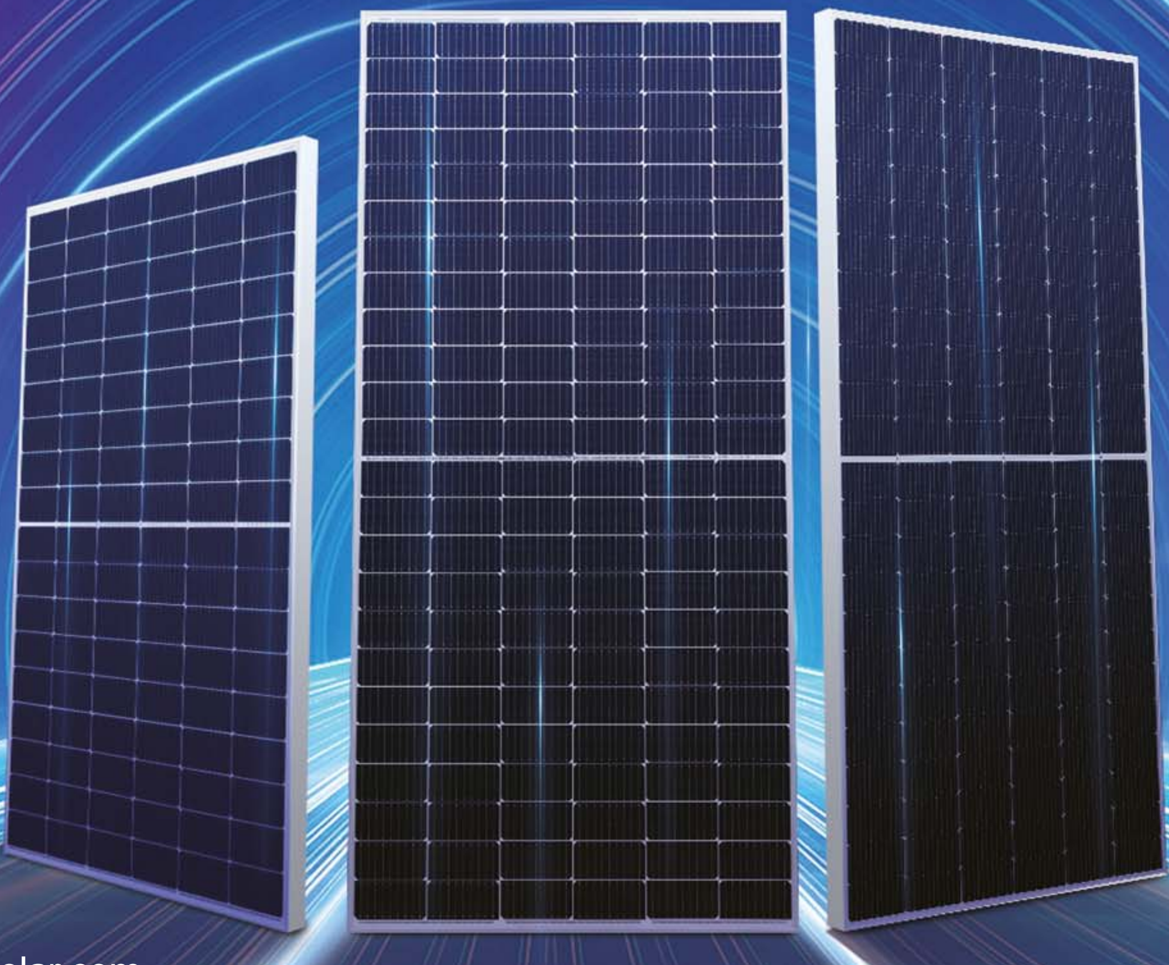

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Overcapacity fears

Canadian Solar halts cell expansion plans amid overcapacity warning

Canadian Solar has warned of solar cell overcapacity next year, slamming the breaks on its own cell manufacturing expansion plans while accelerating on its module assembly roadmap. Canadian Solar chief executive Shawn Qu said the company's manufacturing division was to respond to a projected overcapacity of solar cells in 2022, while Yan Zhuang, president at CSI Solar, would limit investment in certain areas of the manufacturing chain to "avoid falling into the overcapacity trap". In an updated capacity expansion plan provided within its Q3 results, Canadian Solar said it expected to finish the year with around 13.9GW of solar cell manufacturing capacity, up from the 13.3GW of cell capacity it finished Q3 on. However this figure is now not expected to rise at all next year.

Credit: Canadian Solar

designed to allocate INR 45 billion (US$604 million) over five years to back the domestic development of high-efficiency PV modules, this will be increased to INR 240 billion (US$3.22 billion), said India's minister of new and renewable energy, RK Singh. A petition to sanction additional funds for the programme has been approved in principle by the government, Singh told news agency PTI, adding: "We would be exporting solar equipment." Singh added the programme received bids for 54.5GW of solar manufacturing capacity after it was announced.

Capacity expansion

JA Solar to build 5GW module facility

JA Solar has revealed plans to build a 5GW module assembly plant in Chaoyang City, Liaoning Province. In a statement to the Shenzhen Stock Exchange in late November, JA confirmed it had signed an agreement with the local government of Chaoyang City to develop a 5GW module assembly factory and a 2GW hybrid wind and solar power project. Dubbed the 'Jiaoyang Chaoyang Comprehensive New Energy Industrial Base', the facility is expected to require a total investment of RMB10 billion (US$1.56 billion). Of that figure, around RMB1 billion (US$156 million) is required for the manufacturing base, the statement read.Construction of both projects is to be conducted in phases and will be completed within five years.

Tongwei and Trina Solar mark first ramp at 15GW cell, wafer facility

The first manufacturing line at a 15GW solar wafer and cell manufacturing facility in Chengdu co-owned by Trina Solar and Tongwei has begun to ramp. A ceremony to mark the start of production was held in October, just 32 days after manufacturing equipment began to be installed at the site in Chengdu, Sichuan Province, China. The facility is owned by Tonghe New Energy, a joint venture established by cell provider Tongwei and 'Solar Module Super League' member Trina Solar earlier this year. It will produce 210mm solar wafers and cells, doubling down on both manufacturers' commitment to the M12 wafer format.

Polysilicon

TBEA planning 400,000MT of polysilicon production in Inner Mongolia

Chinese energy firm TBEA is planning to invest RMB6 billion (US$938 million) to set up a polysilicon production facility with an annual output of 400,000MT in China's Inner Mongolia region. TBEA will build the facility in two phases, each with 200,000MT of output per year. Construction of the first phase is set to begin in the next month and is expected to be completed within 12 months. According to an agreement signed with local authorities, TBEA will also develop 5GW of renewables projects in Inner Mongolia, with the company looking to take advantage of solar and wind resources near the city of Baotou.

JinkoSolar to invest US$70m in 100,000MT Tongwei polysilicon plant

'Solar Module Super League' manufacturer JinkoSolar is to invest RMB450 million (US$70.3 million) in Tongwei Solar subsidiary Sichuan Yongxiang Energy Technology to help finance a 100,000MT high-purity polysilicon facility. In return for the investment to help construct the plant, Jinko will receive 30,000MT of polysilicon per year and will "share the pro rata profit allocated by the paid-in capital" with Sichuan Yongxiang for the entirety of the joint venture. The initial agreement was announced in November 2020 and, at the time, Tongwei said the contract would run until December 2023.

US manufacturing

First Solar eyes expansion following surging demand

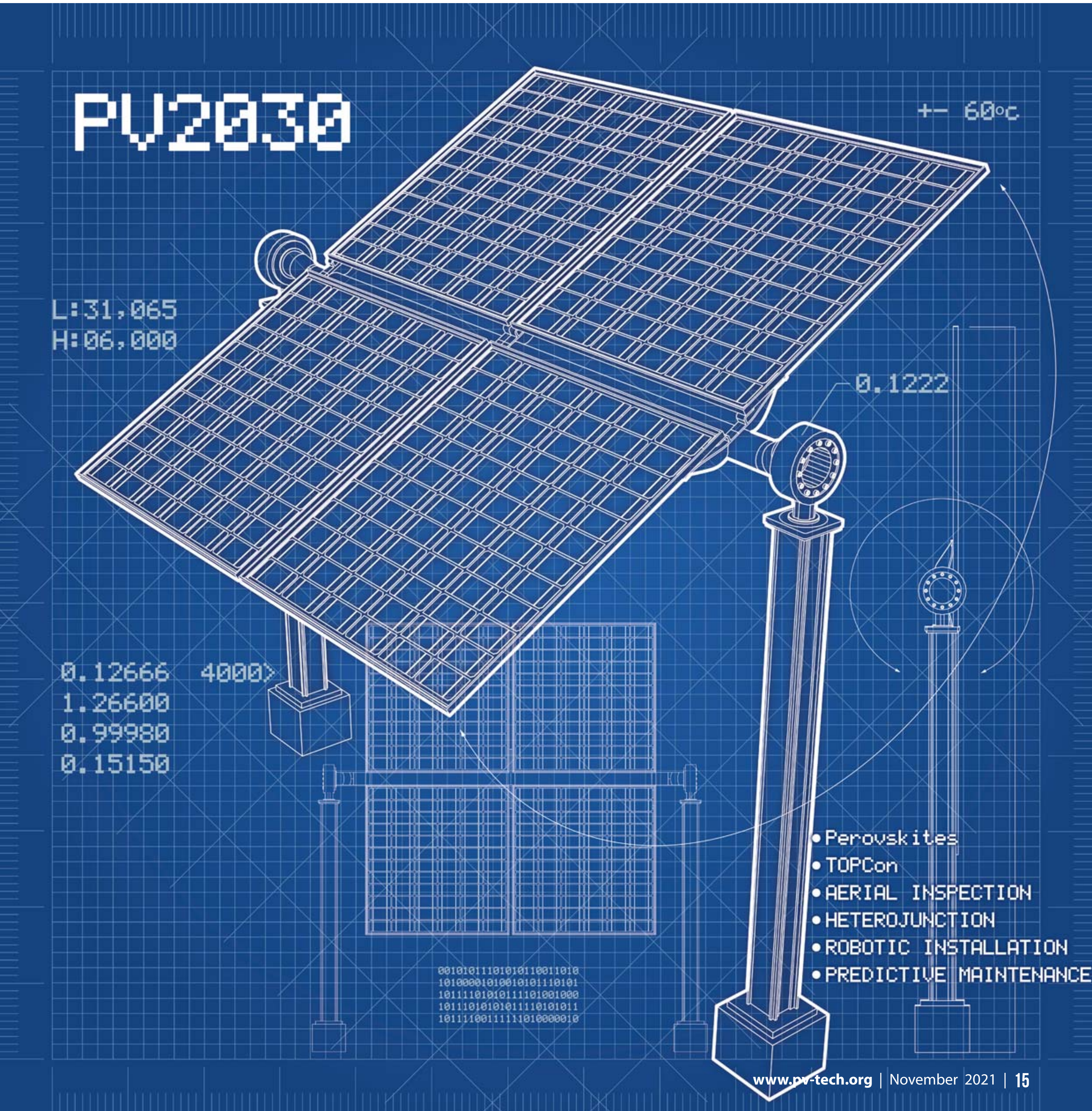
First Solar is actively exploring future capacity manufacturing locations after recording a surge in demand, both domestically and internationally, amidst supply chain obstacles impacting the PV industry. The thin film manufacturer said it was effectively sold out for 2022 and had already secured orders totalling 4.2GW for 2023, with a further 300MW planned for 2024. The company is working towards completing the build-out of its new factory in Pettysburg, Ohio, with its next facility being established in India, CEO Mark Widmar confirmed.

REC Silicon to restart US polysilicon manufacturing

Norwegian polysilicon manufacturer REC Silicon aims to restart its 20,000MT Moses Lake polysilicon facility in Washington during 2023 following a US$160 million investment from Hanwha Solutions. The South Korean company, which wholly owns module maker Q CELLS, bought a 16.67% stake in REC Silicon, which is expected to provide the REC Silicon with enough capital to restart production and Moses Lake and channel further investment into its 2,000MT factory in Butte, Montana that produces semi-conductor materials.

Solar's 2030 blueprint

PV 2030 | Against a backdrop of global action to avert a climate crisis, solar PV faces a critical decade. The generation class must undergo yet another step change, where gigawatts becomes tens and hundreds of gigawatts, if not terawatts. As a result, the industry is undergoing a transformation in technology, scale and relationship with stakeholders from financiers to grid operators. Liam Stoker, Jules Scully and Sean Rai-Roche uncover solar's blueprint for the coming decade.



The solar decade

PV 2030 | The so-called 'king of electricity markets' is rapidly approaching an inflexion point, wherein solar PV will become the most prolific source of new-build power this decade. However to pave the way, numerous hurdles in the technological, manufacturing, O&M and grid fields will need to be surpassed. Liam Stoker, Jules Scully and Sean Rai-Roche discover solar's 2030 blueprint.

Solar PV stands on the precipice of a nearly unprecedented surge in demand and deployment. By the end of this decade, the world's operational solar generating capacity could increase by nearly six-fold, rising from the estimated capacity of 739GW it finished 2020 with to just shy of 5TW by 2030. This is to be driven by an effective and continued collapse in solar's levelised cost of electricity (LCOE), causing demand for the world's cheapest source of renewable power to grow significantly.

The past year has seen countless studies published aiming to chart solar's growth. In the US, the country's Department of Energy's Solar Futures Study found that the country could boast solar generation capacity of 1TW by 2035, by which point the asset class would be accommodating some 40% of its total power demand compared to just 3% today. That will require average annual installs of 30GW by 2025 and 60GW by 2030, with the US having installed around 16GW in 2020. Solar PV, therefore, holds the potential to double and then double again in the US this decade.

In Europe, policymakers are being urged to ramp up the European Union's renewables target to 45% of total demand by 2030, an ambition which would trigger an additional 210GW of solar installations on top of what is already forecasted. That would leave the bloc with a total solar fleet of around 870GW.

Figures like this have become almost commonplace in the solar sector. In practically no time at all, the industry has gone from megawatts to gigawatts, to tens and hundreds of gigawatts. The world's solar capacity will exceed 1TW at some point early next year and, if projections are to be believed, it will top 5TW not long after the decade is out.

It's of little surprise then that with such an obvious and rapid growth trajectory, set to be in such a short amount of time, that the industry is experiencing growing pains.

Annual solar deployment is expected to top 440GW by the end of this decade.

4.96TW

Solar's generating capacity by 2030, according to the IEA.

Growing pains

With annual additions forecasted to rise to in excess of 440GW by the end of the decade, there is an obvious bottleneck in manufacturing capacity to overcome first and foremost. Supply chain constraints have been well documented this year and sufficient manufacturing capacities right the way through the value chain – from polysilicon and silver, aluminium, glass and other materials to wafer, cell and module assembly facilities – will be the limiting factor, at least in the short-term.

Having previously been considered perhaps an industry predominantly led by demand, it is now solely being led by supply. In effect, from today onward, global annual solar additions will primarily be limited by what emerges from factories.

More modules are being manufactured and these are evidently becoming more efficient too. Another inflexion point on the horizon for solar is a looming shift to n-type, triggered by a technology that's more resistant to degradation and more efficient to boot. While other nascent technologies, especially tandem perovskite cells, may have to wait another ten years, by the middle of the decade solar PV will very much have reverted to n-type.

The asset class will, however, face further bottlenecks when it comes to connecting to the grid. It's a relationship that has been fraught previously and continues to be challenging, but in energy storage solar PV has an ideal working partner, while forecasting and grid management is also continuing to improve.

Financiers and developers are also forging new routes to market, consigning subsidies as much to the history books as coal. In the absence of feed-in tariffs, solar PV is finding new routes to deployment in the shape of corporate power purchase agreements. Solar PV is cheap – too cheap, in some cases, as you'll read on – and that price point, coupled with a flourishing corporate social responsibility agenda, is leading more and more businesses to go green.

But as more solar comes onstream, the asset management and operations and maintenance (O&M) industries must not just grow in tandem, but also develop new, more sophisticated ways of ensuring that what's onstream stays on stream and operates as effectively as possible.

Ahead of a critical decade – not just for solar PV, but for the world's climate – this is solar's 2030 blueprint.

Technology – The race to the TOPCon: ***p.18***

Scale – Scaling up to the challenge: ***p.21***

Grid – The grid in 2030: examining the changes needed: ***p.25***

Routes to market – Charting new routes: ***p.28***

Operations – An automated and intelligent future for O&M: ***p.30***

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The race to the TOPCon

Technology | While Mono-PERC is the eminent solar cell technology presently, its dominance is expected to be short lived with n-type TOPCon cells primed to takeover. But when will that technology shift happen? What does it mean for heterojunction? And what does that mean for tandem cells or perovskites? Liam Stoker finds out

Credit: Hevel

Heterojunction cells are just one n-type technology being explored by manufacturers presently

There's an important caveat to make with any forecast relating to the solar industry: it's a perennially and notably difficult industry to predict and, if anything, this is no truer than on the technology side. The industry shifted to 600W+ modules at breakneck speed and the rate at which nascent technologies and approaches such as TOPCon, heterojunction and perovskites are commercialised is just as uncertain.

But while specific forecasts are difficult, trends and the broader direction of travel is evident. While the adage 'bigger is better' has obviously struck a chord with many in the solar sector in the recent past, wafers, cells and modules are unlikely to get much bigger – physically, at least – than those available today.

Jenya Meydbray, chief executive at module testing firm PV Evolution Labs, believes that in terms of physical size, solar modules have hit a ceiling. Today's installation practices and technologies, coupled with how they are designed to withstand various elements and forces in the field – especially in the face of wind, hail and snow – are designed around modules being of a certain size and standard. Making modules materially larger would require wholesale changes.

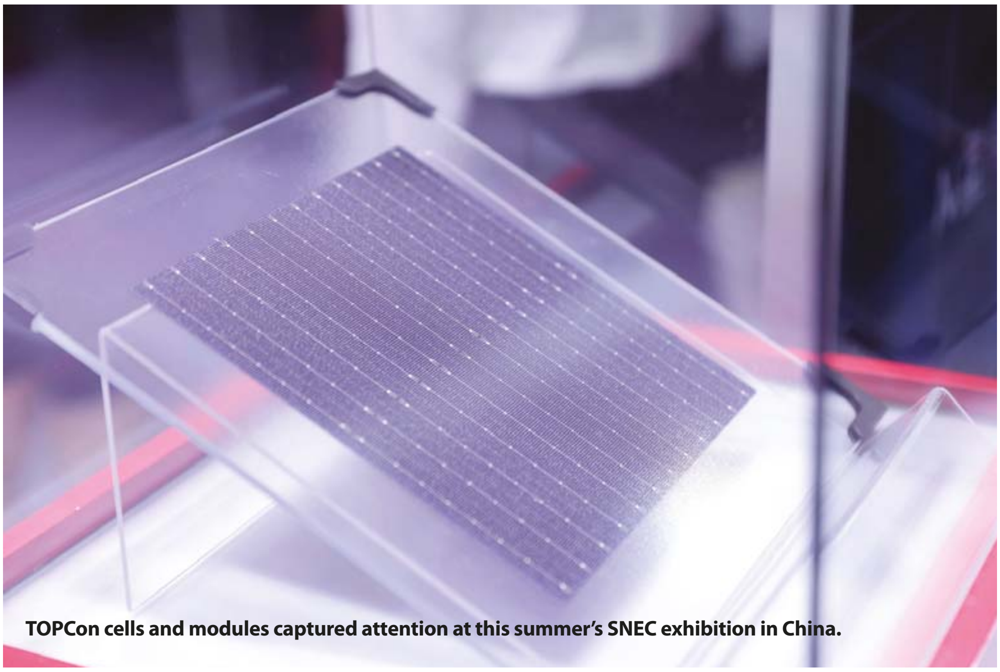
"There's a lot of small adjustments of the design that all stack up to be a pretty big headache for installers or require a lot of planning," Meydbray says.

Any wider, and tracker mounts will have to grow taller – impacting on component and balance of system (BOS) costs – due to the deflection of the middle of the glass travelling farther and the need to prevent it from touching the torque. Taller modules would however catch more wind, exerting more pressure on the module, while also getting closer to the ground at full tilt, requiring taller posts to clear any growing vegetation beneath the panel. Any repowering plans based on legacy designs would also require ripping up and starting again if module schematics changed materially in the future.

Dana Olson, global solar segment leader, Energy Systems at technical advisory DNV, concurs, stressing that "formidable challenges" in pushing wafers and cells would need to be surmounted before any further shift in size. Modules larger than today's modern variants would also place greater structural challenges on a project's design – especially when using the more durable double-glass bifacial format – due to the weight impact. Mounting and tracker providers would need to catch up with any further increase in size and weight.

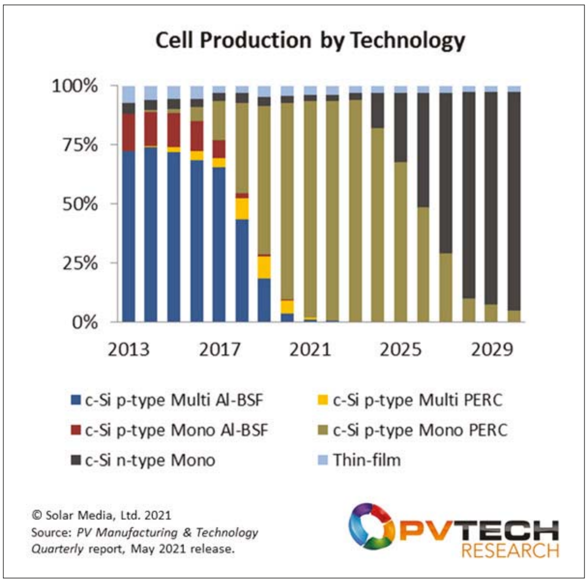
This is also before any consideration is given to shipping, which continues to be a thorn in the side of project developers and component manufacturers alike. With the cost of shipping a container from Asia having risen by at least four-fold in the past year, it's become imperative to ship as many modules and watts per container as possible. Stretching modules any larger could require an overhaul of container packing which could, in turn, reduce the amount shipped in each container, making each watt shipped more expensive in the process.

It is for these reasons that standardisation efforts launched by module majors, intended to set an industry-standard (or as close to a consensus as the industry is likely to achieve) for module sizing and hole positions, has been widely received. Olson says this is particularly pertinent when it comes to developers that may



TOPCon cells and modules captured attention at this summer's SNEC exhibition in China.

Credit: PV Tech.



Credit: PV Manufacturing and Technology Quarterly Report

The technology forecast above assumes a near-complete transition from p-type to n-type occurring between 2024 and 2028.

diversify their module supply to de-risk a project or portfolio and may need to switch out modules across a project for whatever reason.

By extension, more standardised module sizes and mounting positions would help further alignment in system design and build principles which could, in turn, lend weight to automated or robotic installation. Meydbray notes that previous research and testing of robotic field installs has yielded disappointing results, however some start-ups are continuing to explore its potential. By 2030, aided by standardised module design, robots could cut down the time and labour costs of installing a solar farm drastically.

With modules therefore somewhat restricted in terms of size, solar PV is instead being driven to new heights and efficiencies – and indeed closer to the Shockley-Queisser limit – through innovations at the cell level, while the n-type path is one becoming frequently well-trodden.

The shift to n-type

While n-type cells and modules are, of course, nothing new, they have ceded significant ground to p-type mono PERC that has become the mainstay of solar PV today. But that dominance looks set to be eroded and from 2025 onwards, the industry will have shifted firmly to n-type. As the above graph, provided by PV Tech Power publisher Solar Media's in-house market research team shows, p-type Mono PERC cells, which accounted for close to 90% of the market in 2021, will see their market share fall from 2022 and by the middle of the decade, will no longer be the leading PV cell technology available.

Olson says n-type cells are increasingly finding traction in the solar market today. The precise point in time at which they may overtake p-type is, however, difficult to estimate, predominantly because even p-type, as Olson puts it, "isn't standing still either". Cell efficiency improvements continue to be realised and as a result, it's a "continually moving target" for n-type cells to outdo, Olson says.

There could also be a slowing of the technology trajectory caused by the supply chain turbulence that has plagued the industry throughout 2021. Radovan Kopecek, founder of solar research institute ISC Kostanz, notes that when previous polysilicon shortages beset the industry to such a degree back in 2005, global annual solar deployment was at around 2GW. Now, it's firmly up to 200GW. The deployment bottleneck is in polysilicon production, with the industry currently producing polysilicon sufficient enough to make ~190GW of modules each year. Major cell and module producers currently have an output of around 300GW, Kopecek says, meaning as much as one-third of production is essentially "standing still". "This is hindering the big [manufacturers] from rolling out [TOPCon] technology because they're not sure when this feedstock crisis will end," Kopecek says.

TOPCon, or tunnel oxidised passivated contact, is nevertheless all but certain to be the first, or at least quickest, n-type cell technology to gather scale because of the relatively similar manufacturing processes to existing Mono PERC cells. Most 'Solar Module Super League' manufacturers now have TOPCon panels at their disposal and Kopecek is firmly of the belief that TOPCon cells and modules will dominate the industry from the middle of the decade. Olson agrees, citing the relative ease for manufacturers in adapting existing Mono-PERC production lines to produce TOPCon, rather than the wholesale changes necessary for heterojunction.

There are yet kinks in the manufacturing process still be ironed out, not least of all in the deposition of the polysilicon layer. Presently, most are using an LPCVD tool to deposit that layer, however further optimisations are necessary if the industry is to reach efficiencies upwards of 23.5%. PCB deposition tools are in development and become mainstays in the manufacturing process shortly, delivering a breakthrough which Kopecek likens to the aluminium peroxide transition which paved the way for PERC to accelerate.

"TOPCon is only interesting when you have a certain efficiency distance from a PERC average efficiency. What we believe is the real average PERC production efficiency is about 23%, and we are offering TOPCon at 23.5%... that's already possible with LPCVD, but with PCVD it will be possible in the coming six to eight months," Kopecek says.

There is also a slight hiccup, however, in that TOPCon and other n-type cells require higher-purity silicon than their p-type cousins, placing yet further strain on polysilicon producers to ensure that whatever added capacity does come onstream is capable of producing polysilicon of sufficient purity, which may be easier said than done. Earlier this year Daqo New Energy said between 30 – 40% of its poly output is of sufficient purity for n-type cells – the company is providing n-type polysilicon to four of its major clients – however this could increase to 70 – 80% based on industry demand. It's perhaps worth noting however that this polysilicon comes at an added premium of around RMB2/kg (US$0.30/kg), and all at a time when polysilicon pricing is squeezed considerably.

Heterojunction cell manufacturing processes have different requirements altogether, including superior raw material quality to that of TOPCon/PERC production and advanced cleanrooms to prevent spoiling. Kopecek adds that heterojunction cell producers also have not yet solved throughput yield challenges, which are still some way off standard PERC production. Hetero-

N-type panels on display at SNEC 2021

- LONGi Solar – Hi-Mo N – TOPCon
- JA Solar – HJT – Heterojunction
- JinkoSolar – Tiger Pro n-type/Tiger Neo – TOPCon
- Trina Solar – HJT – Heterojunction
- Trina Solar – N-type i-TOPCon – TOPCon
- Jolywood – Niwa Max – TOPCon
- Sunport Power – C10 Pro – Heterojunction
- Canadian Solar – HiHero – Heterojunction
- Tongwei – Shingled HJT – Heterojunction
- Tongwei – Shingled TOPCon – TOPCon
- Risen – NewT@N – TOPCon
- Haitai – HTM470 - Heterojunction

Technology	Equipment	Cell efficiency announcements (%)	Average cell efficiency in production (%)	Available module efficiency (%)	Average voltage potential in production (mV)	Average efficiency potential in production (%)
Al-BSF	Standard	20.29	19.5 - 20	< 20%	670	20.5
PERC	Standard, PERC-based	24.06	22.5 – 23.5	20.2 – 21.1	690	23.5
TOPCon	Standard, PERC-based	25.25	23.5 – 24.5	21.4	725	24.5
Low-cost IBC	Standard, PERC-based	25.04	23.5 – 24.5	21.3	735	25
Low-cost heterojunction	Thin film-based	25.26	23.5 – 24.5	21.9	735	25
Complex hetrojunction	Thin film and electronic industry-based	25.26	24.5 - 25	21.7	740	25.5
Complex IBC	Thin film and electronic industry-based	26.1, 26.6	25 – 25.5	22 – 22.8	740	26

Table 1: High efficiency announcements versus industrial reality of all relevant c-Si technologies on the PV market.

junction modules also have a higher consumption of silver, another material to have witnessed pricing instability within the last 18 months.

Driving change

If such challenges persist, and if the Mono PERC envelope is indeed continuing to be pushed, then what's set to cause the major technology shift that is obviously looming? Simply put, n-type cells and modules promise to deliver inherent benefits in terms of degradation and failure and also cell and module efficiency in production. Furthermore, given their potential average voltage in production, improved temperature coefficients mean modules can boast improved performance in more extreme temperatures.

It is, however, important to decouple the performance in ideal conditions achieved within a testing laboratory using particular materials and that of what can be expected from products from a mass manufacturing line. Table one, provided by ISC Kostanz, documents these differences while illustrating the stated performance improvements over modern and previous leading PV technologies.

Cell and module efficiencies are just one part of the table, however. Future solar technologies and their deployment will be dictated largely by the cost of manufacturing and levelised cost of electricity (LCOE) produced by projects utilising them, with the technologies offering more bang for their buck set to lead the way. While complex structures such as IBC or heterojunction may win out in the production and operating standards, TOPCon still looks set to hold a competitive advantage – at least in the short-term. Kopecek says PERC-based technologies – TOPCon and low-cost IBC, benefit from lower cost structures and thus deliver better LCOEs.

If that's the case, then what are the prospects for heterojunction moving forward and, further forward, perovskite-based tandem cells?

From 3G to 6G

Kopecek uses the analogy of the generations associated with telecoms networks, which have shifted from 3G to 4G and now 5G. If aluminium back surface field (Al-BSF) cells are 3G and modern Mono-PERC cells 4G, then the industry is now making its first significant inroads into the 5G era with the widespread manufacturing and adoption of TOPCon cells and modules. The 5G era will continue to see the adoption of new, more efficient cells, bolstered by TOPCon and TOPCon-IBC technologies, while heterojunction cells and modules will perhaps begin to be introduced towards the end of the decade as lower-cost manufacturing is delivered.

Another material shift could happen from 2030 onwards with the likes of tandem cells and perovskites, however these developments are difficult to predict, Kopecek says, with material improvements needed to manufacturing processes and stability. New research compiled by the Optoelectronic Materials and Device Spectroscopy group, which includes researchers from the University of Cambridge's Cavendish Laboratory and the Okinawa Institute of Science and Technology in Japan, has shed more light on the disorder seen within perovskites that contributes towards rapid degradation of solar cells produced using them, however it's considered that the industry remains more than a decade away from mass-produced perovskite-based cells and modules.

Referring back to his telecoms analogy, Kopecek notes that the leap from Al-BSF cells (3G) to Mono PERC (4G) took a considerable amount of time despite the fact that, barring a tweak to the deposition process, the crystalline silicon cell basis is fundamentally the same. "Coming from a crystalline technology to a tandem [cell] technology with perovskite on top - which are not stable and have reverse characteristics and the deposition technologies are still not yet developed... This will take more than 10 years," Kopecek says.

With TOPCon rapidly asserting itself as the leading solar cell technology of the immediate future, all eyes are on manufacturing and deployment scale. With solar riding the cusp of wave, it's becoming increasingly clear that deployment rests on the upstream sector's ability to scale quickly. ■

Inverter tech trends

As PV modules evolve, so too must the associated components of solar system design, both electrical and structural. Trackers and racking designs are continuing to adapt to modules that are both larger and heavier – all while taking into consideration raw material costs – while inverters are also coming under increasing pressure from modules which produce more power. Zhang Yuehuo, product marketing general manager for PV and energy storage at Sungrow, says the core goal of the inverter is to reduce the levelised cost of electricity (LCOE) of a plant, however this is becoming an increasingly difficult task, especially relating to the product's power density. Zhang says resource is also being channelled into developing more efficient semiconductors, heat dissipation design and algorithm iterations in order to produce inverters fit for the future.

Scaling up to the challenge

PV 2030 | While the technological advancement of solar over the coming decade will play a significant role in driving deployment, actual installations will largely be driven by two factors – manufacturing capacity and national decarbonisation targets. Jules Scully examines how much solar can be made, and deployed, by 2030.

Credit: 8minute Solar Energy.

Heightened decarbonisation targets combined with cost declines in deploying solar will see the technology's share in global electricity supply inch up as countries accelerate installations and some PV manufacturing moves closer to end markets.

Depending on progress towards reaching net zero emissions and the role of renewables in powering hydrogen production, projections of solar deployment in the coming decade vary considerably, although current leading solar markets are tipped to maintain their dominance.

In its flagship World Energy Outlook report published in October 2021, the International Energy Agency (IEA) presented three scenarios to show how the global energy sector could develop over the next three decades. In its net zero by 2050 pathway, installed solar PV capacity would grow from 739GW in 2020 to 4.96TW in 2030, requiring annual additions over the ten years to average at 422GW. By comparison, last year saw 141GW of solar installed globally, according to research organisation BloombergNEF (BNEF).

In the IEA's stated policies scenario, which represents a path based on the energy and climate measures governments have put in place to date, as well as specific policy initiatives that are under development, global solar additions would average at just 181GW to 2030, when total deployed capacity would be 2.55TW.

BNEF analysis, meanwhile, charts three pathways for the world to reach climate neutrality by mid-century, with its 'green' route requiring a trebling of annual solar installation rates by 2030. That scenario would see 455GW of new solar added each year, on average, to the end of this decade, when 5.3TW would be deployed.

The 'green' scenario, which would see solar supplying 17% of the world's electricity, "is the most likely" of the three, according to Jenny Chase, head of solar analysis BNEF, who says around 1TW of the 5.3TW would be for hydrogen production mainly. This route, says Chase, "relies very heavily on solar and wind and also hydrogen to decarbonise industry, because the massive challenge becomes not so much decarbonising electricity, which is relatively easy, but decarbonising making stuff and heat, and agriculture is obviously a huge challenge as well".

Global installed solar capacity would reach 4.96TW in 2030 in the IEA's net zero by 2050 pathway.

In terms of 2030 solar deployment by country, the "top key markets will continue being China, the US and India, with growth also anticipated in major European markets", says Edurne Zoco, executive director of Clean Energy Technology at research firm IHS Markit.

After deploying around 48.2GW in 2020, China's installed solar capacity was more than 253GW at the end of the year, according to the IEA, which said the country had almost a third of the world's installed solar as of 2020.

A recent report from quality assurance company DNV says Greater China will reach 1TW of installed solar in 2026 and will grow its global share of PV from 35% currently to almost 50% in the next ten years.

In the US, the country has been boosted by the Biden administration, whose Department of Energy (DOE) released a blueprint in September showing that solar has the potential of powering 40% of the country's grid, but only if annual capacity additions are quadrupled.

The US added a record 15GW of solar last year, taking cumulative capacity up to 76GW, according to the DOE, which said that for the country to reach the 40% milestone, an average of 30GW of solar PV would need to be deployed between now and 2025 and then 60GW per year from 2025 to 2030, when total solar capacity would reach 550GW. With BNEF recently increasing its solar forecast for the US, Chase says the market is expected to "grow fairly strongly".

Another top market, India, is aiming to reach 280GW of installed solar by 2030, up from the current figure of around 46.3GW. The country is set to be second only to China in terms of solar deployment this decade in Asia Pacific, according to Wood Mackenzie, which expects the market to add 138GW by 2030. The market research firm said although solar tenders have

Exhibit at Japan's largest PV show in March 2022

Japan's largest PV show, PV Expo, organised by RX Japan (formerly Reed Exhibitions) will be held from 16-18 March, 2022 at Tokyo Big Sight.

The event takes place within World Smart Energy Week, with other related exhibitions specializing in areas including fuel cells, rechargeable batteries, wind energy, smart grid, biomass and thermal power.

The Japanese government has announced that the COVID-19 quarantine period has been shortened from ten days to three for fully vaccinated business travellers to reflect the significant progress made globally in the roll out of vaccinations. However, for those still unable to enter Japan, the organiser has made available once again the "remote exhibiting plan" used by over 500 companies for the 2020 and 2021 events. For full details of this option, please refer to our website:

https://www.wsew.jp/en-gb/lp/ex/sew_remote_ex_plan.html

In addition to sister shows held in September and November, the March 2022 edition of PV Expo is expected to attract a large number of visitors, making it a 'must attend' event for any company wishing to expand its business in Japan.

Other shows taking place concurrently in March 2022 at Tokyo Big Sight include:

- FC Expo
- Battery Japan
- International Smart Grid Expo
- Wind Expo
- International Biomass Expo
- Zero Emission Thermal Power Generation Expo
- 4th Resource Circulation Expo
- 1st Decarbonisation Expo

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Organised by: **RX Japan Ltd.**

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*Largest in reference to the exhibitor number and the net exhibit space of trade shows with the same concept.

Scenes from the sister show held in Sep., 2021

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been rolled out consistently, India sees low completion rates.

Among the European countries set to outperform in the coming decade include Spain, where the current government is aiming to support at least 10GW of solar by 2025 through a new renewables auction scheme.

Fitch Solutions forecasts that Spain's solar capacity will grow from 12.3GW in 2020 to 30GW in 2030, when the asset class will account for nearly 19% of its total power generation output. The consultancy expects the country's PV sector to be boosted by government support, declining renewables costs and a sizeable project pipeline.

The manufacturing ramp

Solar manufacturing is expected to ramp up accordingly to enable these deployment targets, overcoming supply chain issues that have plagued the industry in recent months.

Chase says that while manufacturing "is having a bit of a yikes moment right now, because supply chains are just really messed up", the sector will figure out a way to add the volumes necessary. "We can manufacture a terawatt a year of solar modules, it's not really a problem in the next decade."

Zoco takes a similar view, saying that despite current near-term shortages, the solar PV industry has the capacity to expand and serve growing demand this decade, adding: "There will be opportunities for investing in new manufacturing and new technologies as well as an opportunity to bring more manufacturing closer to the end markets."

China is by far the current global leader in solar module manufacturing capacity; according to the IEA, 63% (78GW) of the 124GW of assembled PV modules shipped in 2019 were from China. Its shares of PV cells, wafers and polysilicon ingots further up the value chain are significantly larger.

While markets such as India and the US are pushing to ramp up domestic manufacturing, Chase says the current largest manufacturing hub outside China is Southeast Asia, although "a lot, but not all of the factories there are owned by Chinese companies". IEA figures show 20% of modules shipped globally in 2019 came from either Malaysia or Vietnam, representing 25GW of capacity.

As well as the planned introduction of basic customs duties on module and cell imports, India is looking to boost domestic manufacturing through a production-linked incentive programme that will support the addition of 10GW of integrated solar PV manufacturing plants. Of the 18 bidders that recently submitted around 55GW of applications to the scheme, nine have no prior solar manufacturing experience, according to consultancy JMK Research & Analytics.

"India is trying really hard to get in on the solar manufacturing and is actually planning to build some polysilicon and wafer plants," says Chase, adding that she remains "a little bit cynical" about new polysilicon plants being built by companies with no previous experience of doing so.

> "We can manufacture a terawatt a year of solar modules, it's not really a problem in the next decade."

India's solar manufacturing efforts in the coming decade could be boosted by investments from conglomerate Reliance Industries, which acquired REC Group – a Norway-headquartered manufacturer of p-type, n-type and heterojunction modules – in October, when it revealed plans to use the company's technology in an integrated solar manufacturing facility it will set up in India with an initial capacity of 4GW.

Following recent announcements in the US that include First Solar planning to set up a 3.3GWdc module plant in Ohio that will produce thin film modules, the country's solar manufacturing sector could receive significant legislative support through the proposed Solar Energy Manufacturing for America Act, which would provide credits for US manufacturers at each stage of the PV manufacturing supply chain.

After the policy was announced in June, trade body the Solar Energy Industries Association called for a ten-fold increase in annual US solar manufacturing capacity to reach 50GW by 2030.

"I would say the US, Europe and India are the strongest candidates to promote domestic manufacturing," says Finlay Colville, head of research at PV Tech, who believes the next decade will see the solar industry continue to be production-led, whereby production levels, not market demand, will drive installations.

Despite fresh efforts from government to support domestic solar manufacturing, Zoco estimates that much of the current trends will continue: "The shares of manufacturing outside mainland China are expected to remain small, with the exception of Southeast Asia, outnumbered by bigger capacities expansions announced in China."

Sustainability and grid connectivity hurdles

From setting up new manufacturing bases to securing land and financing for mega PV projects, the solar sector has a range of challenges it will need to tackle to support the global transition towards net zero.

Confident that solar supply chains will be able to cope with increased demand, Chase says grid connectivity could pose more of a problem for the industry. "I think the issues are going to be finding sites, finding especially grid connections, because grid connections are the most valuable thing for the solar industry, and it's not always easy to get them and especially it's not easy to get them in places where you're allowed to build a solar project."

Consultancy EY warned in a report published in October that an immediate upgrade of energy transmission grids is now "critical", suggesting that a 50% increase in grid spending could be needed globally over the next decade if sustainability goals are to be met.

Zoco says the solar sector will face challenges around grid integration and balance due to the intermittency of generation. "The more renewables in the energy mix, the more tension to the grid with high and volatile loads. Increasing penetration of renewables will need to go along with investments in the grid, transmission as well as storage solutions with batteries or other technologies."

With terawatts of solar set to come online in the next decade, Zoco says the sector will also need to confront concerns surrounding the sustainability component of the supply chain as well as environmental, social and governance issues. "This is something that goes well beyond solar PV and also impacts other industries, triggering bottlenecks and disruption," she says.

Despite the upstream and downstream headwinds, the solar sector is set to accelerate deployment at rates that may largely be dependent on government decarbonisation targets rather than the industry's proven ability to manufacture the required equipment. Increased policy support for the energy transition could potentially put the PV industry on a path towards the deployments needed in net zero scenarios. ■

The grid in 2030: examining the changes needed

PV 2030 | The grid of 2030 will span vast areas, be highly automated and require a huge amount of storage as it seeks to connect terawatts of renewable capacity. Sean Rai-Roche speaks to experts about our future infrastructure needs.

Colocated projects with sizeable energy storage facilities will play a crucial role in solving grid issues into 2030.

Credit: ARENA.

The US Department of Energy's (DOE) Solar Futures Study makes it abundantly clear that grid management systems will have to evolve dramatically with the changing nature of power generation and supply. Solar deployment will mushroom this decade – expected to account for around 13% of global generation in 2030 – meaning more and more intermittent supply will have to be handled by the grid.

PV Tech Power spoke with grid management organisations and experts in the US, UK and Europe to discuss what strategies, technologies and relationships will need to be in place by 2030 to manage such changes.

Experts envisage far greater interregional and international cooperation as well as better data on demand and supply to help balance the grid using automated systems. Energy storage has a huge role to play as a flexible resource capable of ensuring supply but there needs to be more developments in long-duration systems.

Contributors agreed that the grid of today is ill-equipped to deal with the monumental changes that need to occur for the energy transition, pointing to a number of high-profile grid outages in recent months, and thus called for greater investment in the physical grid as well as the digital systems that manage it.

Expanding the geographic scope of grid systems

The grids of 2030 will cover far greater areas than they do today. Even those that are not fully integrated into international or even continental agreements by 2030 will still have to operate in a far more collaborative way than they do now. For starters, the evolution of the European electricity system will require "stronger cross-border cooperation to address the challenges that will be regional and pan-European in nature," an Entso-e spokesperson told *PV Tech Power.* The European grid management agency says the grid of 2030 will need "pan-European development of new grid technologies" as well as the "prevention and management of threats that may span over several countries or globally".

Entso-e is currently working on the Trans European Replacement Reserves Exchange (TERRE) project, which is a cross border electricity balancing scheme run by 11 European TSOs designed to share power resources across member states. Randolph Brazier, director of innovation and electricity systems at the Energy Networks Association (ENA), says greater international cooperation will be key to the grid system in 2030 and beyond.

He points to the current levels of European integration with interconnectors between the UK and France, Belgium, the Netherlands, Denmark and Norway, adding that "there are a lot of additional interconnections in the pipeline between those countries and other countries".

Taking this further, India is seeking to ultimately establish a 140-country 'common grid' that will be used as "a channel for the transfer of solar power". The One Sun, One World, One Grid (OSOWOG) project, launched at COP26 on 2 November 2021, will be split into three phases and seeks to exploit geographical differences in irradiance at different parts of the day to ensure a stable electricity supply across participating countries. The first phase will see the Indian grid connected to others in the Middle East, South Asia and Southeast Asia.

"A collaborative effort by all stakeholder countries will lead to reduced project costs, higher efficiencies and increased asset utilisation for all involved," India's strategic investment research unit says. "The implementing mechanism will have to be more carefully worked out. It will involve multiple ministries, authorities within our country, cooperation and careful coordination with other countries," the India-led International Solar Alliance (ISA) said when the project was first announced.

And the trend continues in North America too. "Regionalisation and geographic expansion are a big part of the future," agrees US-based Rob Gramlich, founder and resident of Grid Strategies LLC and executive director of the WATT Coalition. "I think we're going to have large regional power systems and interconnections between countries."

"Right now, southern California exports hundreds of megawatts of excess solar power in the middle of the day to the Pacific Northwest, and then at night excess hydro and wind ships southward," he explains.

Gramlich says this form of cooperation is only set to increase, with similar arrangements already currently in place between US, Mexico and Canada. The Federal Energy Regulatory Commission (FERC) "is trying to get better interregional planning of transmission and to get more integration of markets," says Gramlich.

A FERC spokesperson told PV Tech Power that the transformation of the electricity sector will require new interconnection and transmission resources that have "different characteristics" from those of the past.

Better data and automated systems required

The next area of the grid system that is set to be transformed by 2030 is the quality of data that underpins it and how this is used. Current understandings of grid operations are lacking, inaccurate and there needs to be a greater focus on employing automated practices and artificial intelligence (AI), say experts.

The quality of, and access to, network data has historically been a challenge, says Brazier, as network companies do not share data across their platforms, resulting in siloed information. As a result, the ENA is developing a National Energy System Map, or "Google Earth of energy", that will aggregate the varied data under one system, allowing users to examine network configurations in specific geographic areas and assess issues such as spare capacity and points of connection.

Dan Clarke, head of innovation at the ENA, says the "groundbreaking project" shows how the power of data can be harnessed to "deliver the technologies which will define the industry's net zero future".

Meanwhile, AI and automated operating systems will play a huge part of grid management in 2030, say experts. AI systems will be able to analyse weather forecasting data, historical generation profiles, seasonal output levels and expected demand quantities in real time to present a far more accurate picture of grid requirements.

Studies in both the US and Australia (see p.44) have shown that automated systems can improve forecasting of solar plants, which then reduces the frequency of poor dispatch and allows for the greater penetration of renewables onto the grid.

Brazier is also bullish about the application of AI onto the demand side of the grid. He says that a lot of network processes are currently manual, with customers caring little about the machinations of the grid system or the operating practices of grid managers. "This stuff needs to be automated and super easy," he explains.

> "When I talk about the future of electricity […] it's going to be highly local."

Automated systems can be told exactly what customers are willing to accept and then perform the necessary actions to limit consumption of household electricity use while ensuring those predetermined standards are met, "a bit like how a thermostat works", says Brazier.

A diverse energy storage mix

While the grid system of 2030 will be spread over far greater areas and increasingly automated, it will still require a huge amount of energy storage to ensure flexibility, balance supply and demand and resolve the intermittent nature of renewables. Crucial to this is battery storage, both short- and long-duration, as well as distributed storage and hybrid installations.

While short-term storage has seen its price come down significantly in recent years, long-duration is still very expensive, which has inhibited its widespread rollout, says Gramlich.

"As the cost of energy storage continues to decline, these resources are poised to play an even more important role in the generation mix," adds a FERC representative, with an Entso-e spokesperson adding that longer-term storage "technologies are currently still not competitive enough to make a decisive impact for system adequacy."

Gramlich and Brazier agree that with more R&D and sufficient investment, the price of long-duration battery storage should come down enough for the technology to be far more ubiquitous by 2030. Indeed, in November 2021 the Long Duration Energy Storage Council (LDES Council) was formed at COP26 to facilitate the deployment of between 85TWh and 140TWh of long-duration energy storage worldwide by 2040.

Another vital component of storage in 2030 is the widespread presence of distributed storage technologies. Brazier says storage options like vehicle-to-grid (V2G) storage solutions and heat pumps linked to thermal stores will be increasingly common. "A lot of people think electric vehicles and heat pumps are going to be a massive burden on electric networks, but we see them as an opportunity, they can provide flexibility to us at a street-by-street level, so it's going to be massive in the future."

"When I talk about the future of electricity […] it's going to be highly local," adds Brazier.

Furthermore, microgrids, P2P trading and local community energy hubs will enable consumers to participate in the exchange of energy and flexibility, says Entso-e.

Meanwhile, Gramlich expects hybrid solar-plus-storage projects to be increasingly common over the next decade. Crucially, he sees "storage as a transmission asset" as a completely different market. This would replicate physical delivery systems over large distances by having a battery at both ends of a geographical link.

Amid all these seismic changes lies grid operators. They will have to turn their back on the old, siloed way of doing things and embrace greater cooperation and integration. They will have to facilitate the effective connection of more and more renewables to the grid and ensure that the playing field remains level. No doubt countless political and industrial interests will seek to influence their journey. But there is no clean energy future without a grid that can accommodate it. Let's hope they are up to the task. ■

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Charting new routes

PV 2030 | With subsidies now a distant memory in most markets, solar is increasingly finding itself deployed via government tenders and corporate PPAs. But what are the prospects for those to mature, and to what extent will merchant revenue models emerge this decade? Jules Scully reports.

Credit: 8minute Solar Energy.

With opportunities for merchant projects in a post-subsidy era and corporations turning to solar to decarbonise their operations, routes to market are becoming more diversified, but challenges in the form of financing and price cannibalisation need to be navigated for the sector to fulfil its potential.

Accelerated solar deployment over the next decade will coincide with more cost reductions thanks in part to the growth and development of trackers as well as bifacial and larger modules, according to Wood Mackenzie, which expects technologies such as drones and thermal imaging to make project operations more efficient.

With solar's costs continuing to decline over the next ten years at a faster pace than other technologies, the asset class will become "the clear lowest-cost technology in nearly all markets with favourable irradiance profiles", the market research firm said earlier this year.

The International Energy Agency revealed in a recent report that it expects the levelised cost of electricity (LCOE) for solar PV in the US to fall from US$50/MWh in 2020 to US$30/MWh in 2030. The US National Renewable Energy Laboratory, meanwhile, suggested that the LCOE of utility-scale PV in the country could plummet to as low as US$16.89/MWh in the same time frame.

While previously the pace of solar's penetration of energy markets was constrained by subsidy levels, policy support or corporate buyers looking to decarbonise their businesses, Wood Mackenzie suggests that solar becoming the lowest source of generation means the limiting factors will be investor willingness to take on merchant risk, available transmission capacity and solar's variable generation pattern.

As more solar connects to the grid and wholesale power prices fall, price cannibalisation could threaten the economic viability of some projects.

"It's already something that we're aware of, and we need to mitigate that price cannibalisation in our approach to development and contracting power contracts," says Zosia Riesner, director of power markets for Europe at solar developer Lightsource bp. "Solar cannibalisation is a problem that the energy system and the market will need to adapt to. We can't just ignore it; it won't go away naturally."

The issue is compounded by the rising levels of rooftop solar decreasing the need for utility-scale generation at some times of the day, leading to curtailment – which is already being seen in markets such as California and Australia. The California Independent System Operator (CAISO) region, the part of the grid that covers most of the state, curtailed 5% of its total utility-scale solar production last year, according to the US Energy Information Administration.

"It is expected that the captured prices of PV will present a decreasing tendency, in particular during peak hours," says Andrea Panizzo, head of business development Europe at renewables developer Enel Green Power. "The order of magnitude of this phenomenon [cannibalisation] will depend on the additional PV capacity that will be installed during the coming years, and that will compete at the same time to produce energy and inject it into the system."

8minute has pipeline that includes more than 18GW of solar, but the firm's CEO Tom Buttgenbach says tax equity availability is

To reduce solar cannibalisation and curtailment, Panizzo says it will be necessary to increase the deployment of battery energy storage systems (BESS), which can then sell the stored electricity when prices are higher.

A recent report from DNV stated that despite its higher costs, solar-plus-storage has an advantage over solar PV on capture price, and within a decade the quality assurance company forecasts that about a quarter of all PV installed globally will be installed alongside dedicated storage. By 2030, the capture price advantage of solar-plus-storage over regular solar PV plants will surpass the cost disadvantage on a globally averaged basis, the report said.

After breaking ground on its first solar-storage hybrid project in the US in 2020, Enel Green Power earlier this year acquired a multi-gigawatt portfolio of solar projects in the country, with some of the plants included in the deal to be colocated with BESS to capture additional value streams and add resiliency to the grid.

Giuseppe Cicerani, head of business development generation integrated storage at Enel Green Power, says hybrid solar-plus-storage plants are able to provide at the same time a decarbonised energy bulk, adequacy and flexibility, thus "being a complete and competitive solution for the energy transition".

Cicerani says that the main obstacle for energy storage implementation in some countries is the lack of a regulatory framework that adequately recognises the value of services provided and allows its participation in all energy, capacity and ancillary services markets.

However, in markets where the regulation is already in place and where ancillary services/adequacy are sourced through competitive processes, the energy storage is value accretive and "is being deployed at impressive rates", says Cicerani, adding: "In these markets, energy storage acts as a catalyst for further renewable growth, both at investor level and system level. At investor level, due to the higher profitability of hybrid renewables-plus-storage compared to a renewables-only plant; while at system level, due to the supply of dispatchable capacity and ancillary services."

Financing and diversified revenue streams

With the solar sector set to benefit from further technology improvements and lower construction costs towards 2030, developers spoken to by *PV Tech Power* are largely optimistic for utility-scale solar project financing towards 2030.

Calling the solar power industry "highly investible" due to its growing ability to meet both economic and policy goals, a Wood Mackenzie report earlier this year said renewable procurement for solar has increasingly morphed from just a decarbonisation strategy into a cost-saving business practice, ushering in a new set of investors, including Big Oil.

Recent announcements from oil and gas companies include those by TotalEnergies, which is aiming to cover all the electricity consumption of its European industrial sites from solar power by 2025, while Repsol has increased its 2030 renewables target to 20GW, the bulk of which is expected to be solar PV.

BP, meanwhile, benefits from its 50% ownership of Lightsource bp, which earlier this year raised its solar deployment target to 25GW by 2025 after securing US$1.8 billion in funding provided by ten global financial institutions, including Wells Fargo, Santander and BNP.

"We're not concerned around the availability of capital to finance the transition, and I think that was demonstrated through our recent fundraising," says Riesner. However, with the developer increasing its scale and expanding globally, she says there needs to be a faster speed of transaction and efficiency of execution.

The ability of solar players to secure financing to support large-scale buildouts has also been demonstrated in the US by developer 8minute Solar Energy, which last year upsized a letter of credit facility to US$350 million to help the company accelerate the development of a pipeline that includes more than 18GW of solar capacity and 24GWh of energy storage in California, Texas and the southwestern US.

> "Solar cannibalisation is a problem that the energy system and the market will need to adapt to"

Tom Buttgenbach, CEO of 8minute, says that although financing markets in general "are very healthy and very interested in this asset class", there is one exception: tax equity. This US policy allows an investor to receive a return based not only on cash flow from a solar project but also on federal and state income tax benefits.

"In our case, it's become a challenge just because the tax equity markets right now are very limiting," says Buttgenbach. "For example, I can't finance a merchant power plant because the tax equity supply is so limited that they will only finance highly contracted power plants, and even for those it is questionable if there's enough tax equity today."

Despite potential financing stumbling blocks, developers can be expected to diversify their revenue streams, moving beyond support from renewables auctions to take advantage of solar's competitiveness with wholesale market prices.

To enable returns and optimise projects, Riesner predicts there will be more hybridisation of revenue streams in the coming decade: "You might have some merchant exposure, some assets in auctions, some assets with PPAs, and that becomes more complicated. There needs to be a better understanding of those offtake solutions and the risks."

Low solar PPA prices mean developers are able to benefit from rising demand for cheap solar from a wider range of corporations. With data centres and technology companies historically leading off-site renewables procurement, Wood Mackenzie research says industrial and retail offtakers have become more engaged in the marketplace, contributing to the trend of shorter PPA contracts.

An alternative that has been popular with corporations in the US is the virtual PPA, a contract that doesn't require the physical delivery of energy but instead sees a generator sell its electricity on the spot market and then exchange the floating revenue it receives for fixed payments from a corporate offtaker.

Enel Green Power España recently signed a ten-year virtual PPA with healthcare company Johnson & Johnson for 270GWh per year of renewable power originated from 104MW of wind and solar projects currently under construction in Spain. The agreement provides the offtaker with a financial price hedging and the corresponding guarantees of origin linked with the energy production from the renewables plants.

Panizzo of Enel Green Power says the growth of PPAs will be significantly important for solar projects in the coming years to secure and hedge revenues, compared to merchant prices, which "are usually considered volatile and less attractive to be financed. On the other side, the number of companies interested in signing PPAs with renewable energy is increasing year by year, although in some countries the market regulation does not yet allow for the possibility to structure bilateral PPAs."

Buttgenbach also highlights the flexibility of solar with storage, with plants used to stabilise the grid to create additional revenue streams from trading. "We can network our plants together and we can start integrating our technology with grid technology where if there's an outage, we can react in milliseconds."

He cites recent research from the US Department of Energy that says by 2035 solar has the potential to power 40% of the country's electricity without raising electricity prices thanks to technological improvements and enhanced demand flexibility.

Buttgenbach says: "Doing this renewable transition isn't just a transition to a clean energy world, which we need to do for climate change etcetera, but it's also an economic transition to a much cheaper way to power our planet." ■

An automated and intelligent future for O&M

PV 2030 | Operations and maintenance will face huge changes as automation and predictive analytics transform the way projects are managed, writes Sean Rai-Roche.

Credit: Above Surveying

Drones are already used to conduct a number of imaging-related roles in solar O&M, but this is set to increase over this decade.

In 2030, drones will patrol the skies over solar parks while 'robot dogs' stalk the ground. Together, they will ensure efficient operations, maintain modules and protect assets. Artificial intelligence (AI) and predictive analytics will enable greater energy yields and will better monitor module degradation. And the current skills shortages in operations and maintenance (O&M) will be resolved via widespread training and education programmes.

That is a vision for the future put to *PV Tech Power* by industry insiders. We spoke to companies and experts about what will be required to ensure that a multi-terawatt fleet of global solar in 2030 stays operational.

A 2019 International Renewables Energy Agency (IRENA) Future of Solar Photovoltaic study notes how "the O&M phase is the longest in the lifecycle of a PV project, as it typically lasts 20–35 years", meaning that "ensuring the quality of O&M services is essential to mitigate potential risks". It is crucial that asset owners are aware of the true value of O&M when it comes to project lifecycles and returns on investment, with underfunding and underappreciation a key theme of conversations *PV Tech Power* had.

Mechanised O&M supported by predictive software

Currently, around 80% of the management and maintenance of solar assets is done by humans, says Will Hitchcock, founder and CEO of aerial inspection and data analytics company Above Surveying. "That's the biggest in the energy industry", he says, adding that a big prize for solar will be reducing this level through the deployment of mechanical solutions.

"I think the future will be fully autonomous drones," says Hitchcock. And he isn't alone. Already today in the energy industry, the market for unmanned aerial systems and drones for critical energy infrastructure is estimated to be worth US$1.4 billion this year, according to research firm Guidehouse Insights. It expects the market to increase to US$10.6 billion in value by 2030, with a compound annual growth rate of 24.9%.

In solar, Hitchcock says 'drone in a box' technology will be widespread by 2030. This is where a drone is located on a solar project in a protective box, with auto-landing, take off and wireless charging capabilities. They can then be programmed to deploy at regular intervals to check on the performance of modules across the site using mounted lidar, infrared (IR), multispectral and hyperspectral imagers, all independent of any human control.

German solar O&M company Enerparc agrees that the use of drones in the industry will be increasingly common. "Inspection drones with picture analysis software will be the next big thing," says its COO Stefan Mueller.

The IRENA report notes how "drones are becoming highly suited to the solar industry due to a wide range of surveillance and monitoring capabilities" and how "in recent years they have become popular for their capability to monitor large-scale solar parks in less time than by human inspection".

Contributors also noted how drones will provide enhanced security and protection for solar parks, with sophisticated imaging and built-in alarm systems providing far more security for assets then the current system of human monitoring, which can be hindered by delays and slow response times.

In addition to automated aerial inspection methods, the use of ground-based automated technologies, or 'robot dogs', will become increasingly common to perform ground maintenance, vegetation control and conduct inspections on the underside of modules, say Hitchcock and John Davies, founder and CEO of solar engineering company 2DegreesKelvin.

Presently, a couple of barriers exist to the widespread deployment of such technologies, namely high costs and regulatory hurdles. But Hitchcock believes this will be largely settled by 2030, with prices coming down due to research and development (R&D) and a more favourable regulatory environment as authorities increasingly recognise the value of such systems in driving down the levelised cost

Drones can drastically reduce the time taken to monitor an operational solar plant.

Credit: Above Surveying

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of energy (LCOE) through lower opex costs.

IRENA's report describes how drones and other unmanned technologies "efficiently capture the necessary data and send them to the cloud for analysis in less time and in more accurate form" and the heavy use of predictive software, machine learning and AI alongside automated maintenance technologies was a key theme raised by contributors.

Solar software solutions company PVcase says powerful software solutions employing sophisticated algorithms can measure the expected yield of projects, map this against current output and identify malfunctions and defects in inverters or modules in real time. Its founder and CEO David Trainavicius says the use of predictive technology based on increasingly large datasets is crucial for the industry moving forward.

PVcase's technology collects data from all of its clients' solar projects, aggregates them, combines them with forecasting data and uses predictive software to identify when malfunctions or degradation will occur.

The biggest gap Trainavicius sees in the market is fragmented data sets as projects being rolled out at pace often change hands, in terms of ownership and software management, resulting in less accurate or consistent datasets from which to build predictions and identify maintenance issues. Solving these issues will optimise output, extend the lifespan of projects and give better returns to investors. Moreover, compiling robust data sets from existing plants allow developers to "optimise future assets, even before they're built".

While Mueller says, "machine learning for big data analysis is already there and are working", Davies believes that predictive maintenance software is still in a relative infancy, adding that it will only grow in importance in years to come.

But while using predictive maintenance to estimate when a fault is more likely occur is an efficient way of reducing downtime from failures, it remains the case that faults are occurring. Greater understanding and application of such principles could, evidently, drastically reduce downtimes, and perhaps eliminate them altogether.

Preventing PID

PV module manufacturers generally guarantee a power reduction of less than 20% in the product's 25-30 warranty period. Earlier this year, however, risk management firm kWh Analytics found that solar assets were "chronically underperforming", with modules degrading fasting than anticipated. Annual degradation recorded in the field was observed at around 1%, almost double the previously predicted rate of 0.5%.

Davies says that potential induced degradation (PID) is rife within the industry, with many stakeholders either unaware or ignoring it. He says that one way of addressing the issue is through the use of smart string inverters, which the industry is trending towards. Smart string inverters will come with inbuilt IV curve testing, anti-PID testing and back powering for electroluminescence.

While no drone technology will ever prevent PID as it is caused by design oversight from module makers, Davies says, "advanced drone techniques and analytical software will provide early detection of PID, meaning that PID can be then confirmed by electroluminescence or testing, and then addressed quickly reducing losses for the asset owner."

He says the 'solar boom fleet' of 2011-2017 will be particularly affected by PID in 2030, with so many problems identified that "asset managers and owners won't know what to do first". The key here, Davies suggests, is to "prioritise these issues in a consistent, credible and simple way, so that investment decisions can be made swiftly."

So not only will drones provide an important role in monitoring solar plant performance and protecting assets, but they will also be critical in identifying faults in modules and, in turn, protecting investments through lower retrofitting costs.

Addressing skills shortages in O&M

The pace of solar deployment is far outstripping the availability of skilled workers in the O&M sectors, say Davies and Hitchcock. "The ratio of skills per gigawatt is decreasing," says Hitchcock, who sees this as one of the main challenges facing the O&M space.

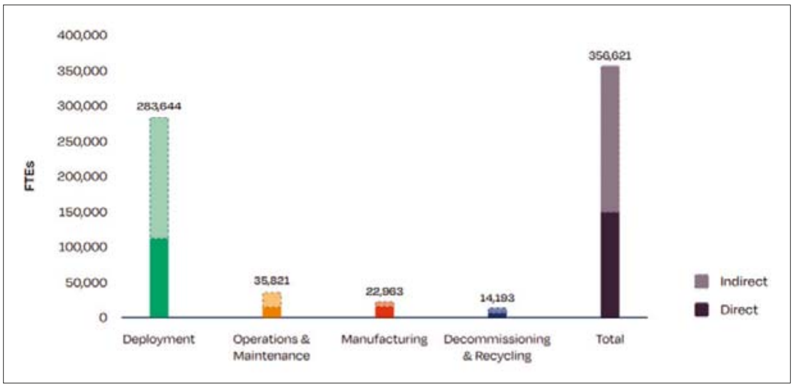
He is part of UK trade association Solar Energy UK's Asset Managers Working Group and says the organisation is having conversations about setting up an academy to train workers in key O&M skills. "I'm not talking about doing a Masters in renewable energy but more teaching people basic engineering skills," he explains, adding that it is needed to tackle the "enormity of the challenge".

SolarPower Europe's latest job report shows how O&M jobs in Europe account for 10% of the total, with deployment making up around 80%, which the report said, "is a consequence of the fact that solar PV has a rather high capex intensity and a low opex intensity".

Mueller says that the maintenance side, composing of technicians and electricians, poses the biggest challenge in the O&M workforce. "Unemployment rate in this segment is zero and no new young people are visible," he adds.

In order to combat this, contributors have urged the industry and companies to establish training centres and work programmes to support the development of skilled O&M workers, without which the industry risks greater than necessary levels of poor plant performance and module degradation.

A recurring theme when speaking with experts and companies was that O&M budgets were often far lower required for the effective maintenance of projects, with it increasingly being left as an afterthought. Given the capital investment into solar project and the importance of strong, consistent yields, O&M should not be overlooked. Drones, automated technologies and predictive software will change the industry significantly in the years to come but the need for highly skilled workers will persist. ■



O&M accounts for just 10% of employment in Europe's solar sector, according to research by SolarPower Europe.

Credit: SolarPower Europe.

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What does it take to build (and maintain) solar in MENA's harsher climes?

MENA | Solar PV has taken off in the MENA region in recent years, driven by positive governmental policy, prominent tenders and decarbonisation targets. But challenges remain, both for smaller companies wishing to enter the market and in the operation of plants. Molly Lempriere takes a look at the market drivers and the challenges of competing.

Despite a slow start, the development of solar in the Middle East and North Africa (MENA) is picking up pace, as countries commit to decarbonisation targets. Should all of the renewables targets in the region be met, for example, there will be 80GW of renewable capacity by 2030, according to the International Renewable Energy Agency, in excess of 50GW of which is expected to be solar PV.

The falling price of solar has been instrumental to this, along with the availability of cheap and sunny desert land, large projects being able to benefit from economies of scale and an increasing number of tenders. As such, even once hesitant oil and gas-rich nations have begun to commit to large solar PV projects.

Countries such as Saudi Arabia, Egypt and the United Arab Emirates (UAE) have been leading the way and have continued to commission large projects, while Oman, Kuwait and Tunisia all have growing project pipelines, and countries like Pakistan and Iraq are engaging in their first utility-scale projects.

The value of operational solar projects in the MENA region is now estimated at between US$5 billion and US$7.5 billion, according to market research group Frost and Sullivan. The total value of projects expected to come online by 2024 is between US$15 billion and US$20 billion, highlighting the increasing growth in the region.

The Middle East's giants

Within the largest economies in the MENA region, an increasing number of very large-scale solar projects have been emerging, with the UAE, Saudi Arabia, Egypt and Qatar leaders in this push.

The Sakaka Power Plant in Saudi Arabia, developed by ACWA Power.

The efforts of the authorities in Dubai and Abu Dhabi have helped the UAE become a frontrunner in the deployment of solar PV, for example. In October 2021, the nation unveiled a plan for becoming net-zero emissions by 2050 – the first country in the MENA region to do so – which includes a goal of 50% clean energy.

Hamid Can Baş, consultant at Apricum – The Cleantech Advisory, suggests that the market may slow down after 2022, as the completion of large projects will bring the country close to its 2030 targets. The market size will likely be determined by whether other nations beyond the emirates of Dubai and Abu Dhabi follow suit and announce tenders.

Another giant is the Kingdom of Saudi Arabia, which is targeting 27.3GW of renewables – weighted heavily towards solar at around 20GW – by 2023, and 58.7GW by 2030. The country's Renewable Energy Project Development Office (REPDO) ran an initial two tenders, one for solar and one for wind in 2017. The 300MW Sakaka solar project from state-owned developer ACWA Power won a year later, with a winning bid of US$0.0236/kWh, which at the time was a world record.

The completion of REPDO rounds two and three, along with other bilateral agreements for large-scale solar projects "paints a bright picture for the future", adds Can Baş. The localisation requirements within these auctions additionally signal the "development not only in PV plant installations but also an emerging PV industry".

The Sakaka solar project's tariff record has been broken a number of times since the auction however, including by Qatar's first solar tender which saw a price of just US$0.01747/kWh. The resultant 800MW Al Kharsaah Solar PV IPP Project is being developed by a consortium of French energy giant TotalEnergies (49%) and Japanese conglomerate Marubeni (51%).

Beyond the PV heavyweights, other MENA countries are beginning to bring in decarbonisation targets and tendering to build out solar. Algeria for example updated its Renewable Energy and Energy Efficiency Development Plan in 2019 to target 5.6GW of solar PV by 2030. In 2019, the nation had around 343MW of renewables, the bulk of which is made up of solar PV, according to the Middle East Solar Industry Association (MESIA).

> "A lot of the numbers they report, they're completely hypothetical, they're not really what the project is being paid"

Across North Africa in general, there has been steady growth in recent years with renewable energy production growing by 40% over the last decade. This meant

4.5GW of wind, solar PV and solar thermal capacity were added to its renewable power fleet. The region's renewable generation capacity grew by 80% over the same period and by almost 560% if you exclude hydropower.

Much of this has been driven by policy, laws and regulations. Egypt, for example, introduced feed-in tariffs in 2014, which was followed up by allowing long-term power purchasing agreements in 2017, making it more attractive to independent power producers. The impact of these changes can be seen in the development of the 1.8GW Benban solar park.

Transparency and the growth of markets

While there has undoubtedly been significant progress made in the region, encouraged by cheap project financing and supportive tax regimes, a number of key challenges remain. Some of these are due to the shape of the market currently as thus far it has been dominated by large-scale, government-run tenders, and "the absence of other opportunities such as participation in merchant electricity markets [has] made the market development solely reliant on PV auctions", says Can Baş.

Within this, there is a lack of transparency in most parts of the region in terms of the bidding process, says Ibtihal Abdelmotteleb, solar analyst at Wood Mackenzie, making identifying the true cost all the more challenging.

"A lot of the numbers they report, they're completely hypothetical, they're not really what the project is being paid," Jenny Chase, head of Solar Analysis at BloombergNEF, says. "And usually [the state's] utility is owning the project. So there's also a bit of confusion over what that represents, and they're not very transparent about it."

The record low prices seen in the region – whether they're as low as stated or not – are a significant challenge to smaller players in the market, as they simply cannot compete within an auction setting. As such, the market has been dominated by energy majors and state-owned entities like Saudi Arabia's AWCA, Abu Dhabi's Masdar, Dubai Electricity and Water Authority (DEWA) and Qatar's Siraj Energy.

While a feature of the MENA region currently, this prevalence of government-backed companies is not a unique trait, says Heymi Bahar, senior analyst for Renewable Energy Markets and Policy at the International Energy Agency (IEA), and more representative of an industry in its early stages.

"In some of the places, there have been preferential land allocation and preferred grid connection, which may or may not be included in the bids, we don't know," he says. "But I think it's important to understand that it's driven by the policies, and in the initial phases of this deployment, these policies are key."

This prevalence of government companies and financing has so far helped to achieve low costs, and is a trend we've seen in other regions such as China and India, Bahar says.

These low costs will be further challenged by rising technology prices, with Chase suggesting the amount of solar built in the next year could potentially slip and the record low auction rounds seen in recent years will likely drop off in the short term. Can Baş agrees, saying it will take two to three years before module prices drop to 2020 levels following the recent rises in polysilicon, steel and shipping costs.

> "Profit margins of PV projects in the region are razor thin as a result of very competitive auction process"

"Profit margins of PV projects in the region are razor thin as a result of very competitive auction process," he says. "Any increase in component prices can disrupt the finances of the project. Developers who have the luxury to postpone their projects opted to do so with the hopes of relaxing prices next year."

As such, companies that have the ability to postpone their projects are likely to do so, while those with a close deadline or a backlog of projects will need to "take the hit" he says, and deliver with even lower margins or at a loss.

Given the strong role of government on the development of solar currently, the impact of the fluctuations in the value of oil is likely to also challenge the rollout of projects. In particular in countries like Kuwait, Iraq or Algeria, lower oil prices could reduce the appetite of government to pursue renewables.

Broadening the markets' margins

There are a number of actions that could be taken to develop these markets further, including holding more frequent auctions that would help market players maintain a healthier project pipeline. This would additionally help to increase visibility in the market, which in itself would increase investment appetite.

Subsidy reform that ended the artificially low fossil fuel prices in the region, would help cost-effective solar tariffs, which ultimately would lead to bill savings through solar, says Abdelmotteleb. Additional steps that could be taken include promoting competitive local markets, a knowledgeable customer base

The 1.8GWp Benban solar project in Egypt.

Credit: Scatec.

and Opex savings.

"With the support of government initiatives, local developers [could] play a role in promoting the perception of the energy transition in the Middle East," she continues. "Flexible business models and a clear understanding of Opex savings will further drive consumer enthusiasm and C&I installations."

Beyond the large-scale project, rooftop solar poses a opportunity for smaller developers and start-ups, which could help broaden the solar market as a whole in the region. For example, the Sahim programme in Oman, which provides an export tariff for excess generation from rooftop solar PV fed into the grid, or Shams Dubai, a rooftop solar programme introduced in 2015 that allows net metering, ensuring consumers are paid for surplus generation which is fed to the grid, have both seen some success.

"Besides state-owned developers, currently the C&I sector is developing strongly," adds Abdelmotteleb. "Local developers are playing a main role in the market for different C&I offtakers such as retailers, schools, universities, factories, agriculture sector, as well as the mining sector."

Operational challenges

Once the projects are developed, there remains operational challenges to be considered, including the impact of soiling on operational solar farms, with the conditions of much of the desert landscape leading to a build-up of dust on panels and other equipment. Dr Ben Figgis, research program manager at the Qatar Environment & Energy Research Institute (QEERI), says in Qatar they see a reduction in generation of around half a percent a day due to soiling. Therefore without cleaning, power generation can fall by roughly 15% over a month, depending on the time of year.

"That's a critical challenge that needs to be dealt with," he adds. "I think there's a lot of technologies that are being developed and there is space for a lot of innovation."

It remains a fairly nascent area of technology development, with the majority of focus falling on automated cleaning robots. Beyond the panels themselves – with bifacial mono PERC modules emerging as the dominant technology in the region – the impact of soiling on other components must also be considered.

The MENA region covers over 15 million square kilometres, and includes a multitude of different environments. Dr. Veronica Bermudez, senior research director of the Energy Center at QEERI, notes that not all deserts are the same, so while many in the region are very dry, there are also humid desert regions adjacent to the coast, which results in conditions featuring high salinity.

The type of dust in the atmosphere varies with the Sahara typified by fine dust, says Chase. "So unlike, say, the Atacama Desert in Chile, you've got a lot of soiling, and often dust in the atmosphere reducing the energy going in," she adds. "So although it is pretty sunny, it's not actually as sunny as you might have thought."

Growing targets and growing solar

Despite the challenges, further growth is expected across the region in the coming years, in particular given the ever increasing solar, renewable and decarbonisation targets announced.

This includes giants like the UAE publishing its UAE Net Zero by 2050 Strategic Initiative in October 2021, which includes a target of 14GW of carbon-free energy by 2030. But also smaller markets, such as Israel targeting 30% of electricity production from solar energy by 2030, Morocco is aiming for 52% renewable energy by 2030 and Oman has set a target to derive 20% of electricity from renewables by 2027 in its National Energy Strategy.

"I think North African countries will continue to build substantial amounts of solar because they often have quite serious power issues. And I think probably they will continue to be big contracts with the big companies in the richer countries," says Chase, adding that in the MENA region more broadly, she expects "a bit of sense coming into the region and the realisation that we can just build a couple of gigawatts every year and it doesn't have to be a big drama" as countries move away from reputational competition as capex jumps in the short term due to module prices. ■

The appeal of a green gas: solar-powered hydrogen in MENA

An emerging technology gaining attention in the MENA region is green hydrogen, which could offer an option for the storage of surplus renewable generation, aid balancing supply and demand, and as a multipurpose energy vector, offer a potential route for decarbonising harder to abate sectors.

The Middle East in particular has significant green hydrogen potential, with research from Wood Mackenzie finding that almost 60% of proposed green hydrogen export projects are located in the Middle East and Australia. These are principally targeting markets in Europe and Northeast Asia.

"In addition to investing in renewables to slash emissions and enhance energy security, countries and industries are now looking to electricity-based fuels and feedstocks, and hydrogen could be the gamechanger," said Wood Mackenzie research director Prakash Sharma in a report. "A key differentiator is hydrogen's massive potential in traded energy markets. Low-carbon hydrogen and its derivatives could account for around a third of the seaborne energy trade in a net zero 2050 world."

The first green hydrogen project in the MENA region was inaugurated in May 2021 by Sheikh Ahmed bin Saeed Al Maktoum, chairman of the Dubai Supreme Council of Energy and chairman of the Expo 2020 Dubai Higher Committee. The Mohammed bin Rashid Al Maktoum Solar Park in Dubai will work as a demonstrator plant for the potential of green hydrogen, along with a number of other technologies on the site including battery energy storage.

Mohammed bin Rashid Al Maktoum Solar Park includes 1GW of solar-powered hydrogen capacity, built with the support of German industrial conglomerate Siemens. The solar park has two operational solar plants currently – the 13MW Phase 1 plant and the 200MW Phase II plant – and a further 800MW of PV capacity is under development.

It will support the Dubai Clean Energy Strategy 2050, according to DEWA, with the emirate aiming for 75% of its total power capacity to come from clean energy sources by 2050.

At the inauguration of the hydrogen project, Dr Sultan bin Ahmad Sultan Al Jaber, minister for state for the UAE, said being an early adopter of a hydrogen economy will be instrumental in achieving sustainable economic growth in the country.

"The green hydrogen project represents a major step forward in this direction and will greatly accelerate our production of renewable and clean energy sources and contribute to our on-going climate action efforts."

Beyond the Mohammed bin Rashid Al Maktoum Solar Park, a joint venture made up of Air Products, ACWA Power and NEOM is developing a US$5 billion hydrogen project in Saudi Arabia. NEOM Green Hydrogen will include a 1.2 million tonne a year green ammonia plant, with more than 4GW of solar, wind and storage powering the electrolyser onsite when production begins in 2025.

The largest green hydrogen plant in the world meanwhile is set to be built in Oman, where 25GW of wind and solar will be used when the plant in Al Wusta governorate on the Arabian Sea is completed in 2038.

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Is the Glasgow Climate Pact a boon for solar, or a COP out?

COP26 | The sun wasn't shining in Glasgow for COP26 and many in the solar sector lamented the lack of mention in countries' pledges. Nonetheless, some vital announcements were made that will be crucial to the industry's growth and its role in reaching net zero, writes Sean Rai-Roche.

Credit: UNCC

It was billed as the last chance to save the world in the 'decisive decade' for climate change but COP26 did not result in the commitments that many activists, campaigners and climate vulnerable nations had hoped for. While there have been some positive multilateral organisations formed to tackle key emissions causes, countries' individual commitments or Nationally Determined Contributions (NDCs), have not been enough to limit the world to 1.5 degrees Celsius of warming above pre-industrial levels.

Analysis from renowned climate analysis group Climate Action Tracker (CAT) shows that under current national plans, the world would be headed for 2.4 degrees of warming, which climate scientists have said would be disastrous. While other analyses, including by the International Energy Agency (IEA), have said pledges could result in 1.8 or 1.9 degrees of warming, these place too much weight on net zero targets in the second half of this century, resulting in a more favourable outlook, says Taryn Fransen, an international climate change policy expert at the World Research Institute (WRI).

The draft text of the Glasgow Climate Pact called on all parties to "accelerate the development, deployment and dissemination of technologies, and the adoption of policies, to transition towards low-emission energy systems, including by rapidly scaling up the deployment of clean power generation and energy efficiency measures".

If it wasn't already, the role of renewables has been made abundantly clear. While this is no surprise to those of us in the solar industry, with energy consumption accounting for around 75% of global emissions according to the WRI, it does give our sector the ammunition and added urgency required to make an even more compelling case for the role of solar PV in decarbonising economies, protecting the natural environment and future proofing societies from the climate crisis.

So, what targets and policies have been set for renewable power generation and solar more specifically? Which countries have been the most ambitious when it comes to solar deployment? And what state support will there be to facilitate such deployment?

The Glasgow Climate Pact "kept 1.5 degrees" alive, said COP26 chair Alok Sharma, however critics suggested it was merely on life support.

India pledges achievable, realistic targets

India entered COP26 as one of the countries to watch and it was likely it would transfer its domestic policy of reaching 450GW of renewable energy by 2030 into its NDC. This has essentially happened, with the country committing to 500GW of renewables by 2030, including nuclear and large-scale hydropower.

While its pledge to reach net zero by 2070 was received with disappointment in many quarters, it was never likely to be any sooner given the country's historically low emissions and growth requirements, says Ulka Kelkar, director of the World Research Institute in India. Many analysts predict that 2070 is the earliest date India can reach net zero. Kelkar says that a net zero date had become a hotly contested debate in India and the fact that one was set was a positive.

On its 500GW target, "people don't fully appreciate the scale of these targets," says Kelkar, adding: "500GW by 2030 means India will have to install the UK's total renewable capacity of 45GW every year, for 10 years". While India has missed some of

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its short-term targets – it was planning on reaching 100GW of solar PV by next year, which it will almost certainly miss – it has witnessed a "spectacular rise" of solar PV, according to the IEA's India Energy Outlook report, with this sure to continue under its current NDC.

But India's domestic manufacturing capacity is not enough to meet its current climate goals, says Saon Ray, senior fellow at the Indian Council for Research on International Economic Relations (ICRIER). In response, the country is eyeing a build out of PV manufacturing capacity, which it hopes will spur domestic deployment and protect itself from any market shocks. The head of India's Ministry of New and Renewable Energy (MNRE), RK Singh, has openly stated the country's desire to challenge China's dominance in solar manufacturing.

"India needs to develop domestic solar manufacturing capacities and reduce its dependence on imports, which at present is close to 90%, of which 80% is imported from China, to avoid disruption in the future," says Ray, adding that while this should help to scale up domestic manufacturing, imports will still rise in the short term until the basic customs duty is introduced next year. India also lacks access to certain key minerals needed in PV manufacturing and is trying to solve this via joint venture agreements, she adds.

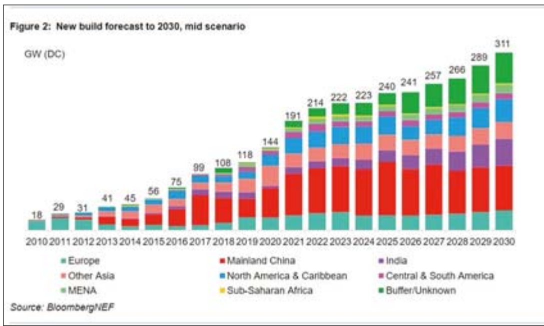
Kelkar does notes that the other four pledges made by India during COP26 are ambitious and, if realised, would send a very strong signal about its attitude to decarbonisation. Other surprising 2030 targets include an absolute reduction in its emissions, achieving carbon intensity reduction of 45% over 2005 levels and sourcing 50% of energy requirement from renewables, although Kelkar says this last point has since been clarified by the Indian government to refer to installed capacity and not generation capacity.

India also launched the Green Grids Initiative-One Sun One World One Grid (GGI-OSOWOG or OSOWOG) transcontinental solar grid project at COP26, which aims to connect 140 countries through a "common grid" and will require the input of myriad governmental agencies and private companies.

India was, however, jointly responsible, along with China, for the last-minute watering down of language on coal, modifying the pact's wording to refer to a 'phase down' rather than 'phase out', much to the dismay of the majority of attending nations.

Key COP26 climate targets set by major polluters

- China has committed to 1.2TW of renewables by 2030
- India has committed to 500GW of renewables by 2030
- The US has committed to deriving 80% of its electricity supply from renewables by 2030
- The UK has set a target of 100% renewable electricity by 2035
- Saudi Arabi, which was accused of obstructing climate progress, has refused to divest from oil and gas production
- Japan is to source around a third of its power from renewables and will cut its emissions by 46% by 2030 compared with 2013 levels.
- South Korea has pledged to cut its emissions by 40% by 2030, up from 26.3%, with 30% of power from renewables, up from 7% in 2020.
- The European Union has pledged to source 40% of its final energy demand from renewable sources.
- Russia did not strengthen its climate targets, rated 'highly insufficient' by CAT, and intends to reduce emission by 30% by 2030, based on 1990 levels.



Source: BloombergNEF

India's solar new builds are expected to increase significantly over the next decade

China sticks to its guns

On 29 October, just before COP26, China submitted its highly anticipated NDC that was branded 'disappointing' and 'a missed opportunity' by pundits. It was condemned by climate activists who said it represented little progress on its 2016 targets, despite massive reductions in the cost of clean energy.

While the targets contained in the new NDC are an improvement on the 2016 submission, they are no more ambitious than the objectives put forward by Chinese President Xi Jinping at the Climate Action Summit hosted in the UK last December.

Nonetheless, China, which has over twice the capacity of solar PV than the US and Europe combined, has committed to 1.2TW of renewable capacity by 2030, more than double its current level of 535GW.

The country's NDC also said it will lower its carbon intensity by more than 65% by 2030 from 2005 levels and increase its share of non-fossil fuels in its energy mix to around 25% by 2030.

"It wasn't an update from what they announced in 2020," says Ryan Wilson, a climate and energy policy analyst at CAT. "There has been a slight language change, so before China was going to peak emissions 'around' 2030 and now it is peak 'before' 2030 but apart from that not much has changed."

"But 1.2TW of renewables is nothing to sniff at," says Wilson. "It's not bad across the board. China's probably a good representation of how things have gone in general [at COP26] – there has been an incremental step up, but we're past the point at which we can celebrate incremental increases. We need transformative commitments, and we didn't get that from China."

"And a lot of countries haven't stepped up," he adds.

The US arrives empty handed but acts as orchestrator

The US was hoping to 'step up' by arriving at COP26 with one of the largest infrastructure packages the world has ever seen, but President Biden's Build Back Better bill is yet to be passed.

At the start of the month US lawmakers passed a US$1 trillion bipartisan infrastructure deal that will see the country's power infrastructure modernised to support new renewables projects. But Congress is still at a deadlock regarding the US$1.75 trillion reconciliation package that includes nearly US$570 billion for tax credits for renewable energy – including solar PV – as well as incentives to spur domestic PV manufacturing.

Speaking at the time of the announcement, US President Joe Biden called the bill the "most significant investment to deal with the climate crisis ever" and said it will position the country to achieve its target of a 50-52% emissions reduction by 2030.

But this bill has not yet been passed because of resistance from Democrat senators Manchin and Sinema, with rumours of the watering down of some areas, although the White House has reaffirmed the centrality of renewables to the bill.

And current infrastructure funding is by no means enough to get the US on track to meet its NDCs. "It's not going to get us to the NDC by any stretch," says Fransen, "so we're really watching the reconciliation bill, which has, in its current version, very significant climate provisions".

Nonetheless, the conference was not fruitless for the US, which joined the International Solar Alliance (ISA), took the lead on multilateral agreements on

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deforestation and methane and signed a joint agreement with China that, while thin on detail, agreed to cooperate on climate change more closely and was a positive step forward for the two powerhouses who have recently been embroiled in bitter political and trade disputes.

South America shows progress

When it comes to South American countries, CAT rates most of their NDCs as 'insufficient' or 'highly insufficient' for keeping 1.5 degrees within reach. Countries currently with net zero commitments on the continent include Brazil, Colombia, Argentina, Uruguay, Peru and Costa Rica (government positions, but not legislated) and Chile (legislated), says James Ellis, BloombergNEF's head of research in Latin America. "We can expect to see redoubled efforts to support the growth of solar and other sources of renewable energy," he adds.

While specific policies under net zero pledges in South America have not been explained in full, Ellis says solar PV will play a "very significant" role in the continent's decarbonisation. "Despite uneven support for it across the major markets of the region, solar has generally been growing the fastest of any source and its levelised cost of energy (LCOE) has been falling the most rapidly," he explains.

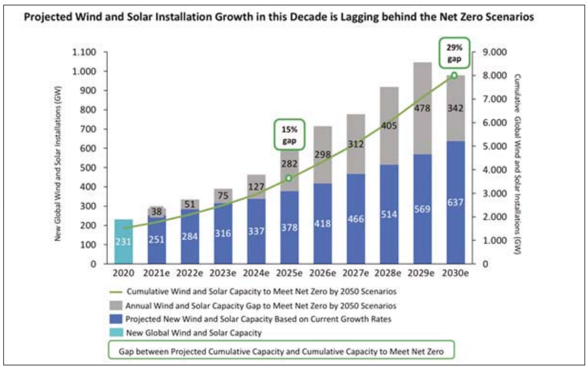
"In many markets of Latin America, solar is and will continue to be the most competitive source of new bulk generation. This means of course that solar is an essential ingredient in the mix as countries, cities, companies and consumers across the region push to decarbonise."

Ellis notes another few important policy announcements that were made by South American countries at COP26: Chile's Ministry of Energy's joint announcement with power company AES to increase battery energy storage capacity to 1,563MWh, many times what the country (or region) has today; Colombia's announcement that it is to hold its next auction in 2022, "which will likely be important for solar," says Ellis; news of Brazil's hydrogen strategy being set for release next year; and Argentina's agreement with Australian mining company Fortescue's proposal to invest US$8.4 billion in a 2.2 million tonnes per year green hydrogen export project in Patagonia.

Key COP26 announcements

- Global Renewable Energy Alliance (GREA) formed by Global Solar Council (GSC) and Global Wind Energy Council (GWEC).
- More than 100 world leaders, including Brazil, pledged to end deforestation by 2030.
- The Global Methane Pledge aims to limit methane emissions by 30% compared with 2020 levels.
- The world's two biggest emitter, the US and China, sign commitment to enhance climate action in the 2020s
- US joins International Solar Alliance (ISA)
- OSOWOG initiative launched
- The Global Energy Alliance launched a US$10.5 Billion fund for emerging economies
- Over 40 countries promised to phase out coal
- Financial entities with assets totalling US$130 trillion agreed to back "clean" technologies, such as solar, and direct finance away from fossil fuel industries.

There is still a significant gap between predicted installations and where countries' need to be to hit net zero



Source: See references (1)

EU and the UK need to match words with action

In July, the EU pledged to reduce emissions by at least 55% by 2030, as part of its 'Fit for 55' policy, and to source 40% of its final energy demand from renewable sources. SolarPower Europe estimates this will require 660GW of solar power installed by 2030, amounting to 58GW installed each year.

New EU commitments at COP relevant to solar were few and far between but it did announce a 'Just Energy Transition Partnership' with South Africa – that will support South African decarbonisation of its electricity system – and the US$1 billion 'EU-Catalyst partnership' with Bill Gates and EIB President Werner Hoyer, which aims to boost investments in "critical climate technologies".

While many individual states were critical of slow progress and watered-down language at the conference, the European Commission said the event had helped get the world closer to 1.5 degrees of warming.

The UK has some of the world's strongest climate targets, but they are not necessarily backed up with funding or policies, says Wilson. The country has set a target of 100% renewable electricity and has pledged to reduce its emissions by at least 78% by 2035, compared to 1990 levels, along with its net zero by 2050 target.

To do so, it has earmarked around US$1.34 billion to support the electrification of UK vehicles, US$2.02 billion for net zero research and innovation and US$5.24 billion for the decarbonisation of homes and buildings. At COP26, UK chancellor Rishi Sunak also told companies and financial institutions in the City of London to submit public plans on how the world's largest financial centre aims to reach net zero in line with the UK's 2050 commitments.

"The policies and spending brought forward in the Net Zero Strategy mean that since the [UK's] 'Ten Point Plan', we have mobilised £26 billion (US$35 billion) of government capital investment for the green industrial revolution," says the UK government.

However, Wilson says the current spending and policy commitments in the UK do not match up with their targets and more funding needs to be made available for the country to have any chance of achieving such lofty commitments.

Another shot in Egypt

Despite the many positive, promising pledges made at COP26, there was an overwhelming feeling that not enough had been achieved at this seismic conference. Current commitments still put us on a trajectory of 2.4 degrees of warming and there were not enough mentions of the role of solar, one of climate change's biggest adversaries, at the two-week event.

The lack of progress has been so acute that many, including the architects of the landmark 2015 Paris Agreement, called for countries to submit further upgraded plans at the next summit, COP27, which will take place in Egypt. This will now happen. But that is a year away and a lot can happen, or not happen, in a year. ■

References

(1) Source: GWEC Market Intelligence, SolarPower Europe GMO 2021, IEA Net Zero by 2050 Roadmap (2021). Projected new wind capacity from 2021-2030 is based on GWEC's Q1 2021 Global Market Outlook; projected new wind capacity from 2026-2030 assumes a ~4% CAGR, same as the projected CAGR from 2021-2025; projected new solar capacity from 2021-2030 is based on SolarPower Europe's Global Market Outlook; projects new solar capacity from 2026-2030 assumes a ~14% CAGR, same as the projected CAGR from 2021-2025; Capacity gap figures are estimations based on the IEA Roadmap milestone for 2030. This data represents new and cumulative capacity and does not account for decommissioned projects.

Product reviews

Modules | JinkoSolar's next-generation n-type ultra-high efficiency Tiger Neo Modules

Product outline: JinkoSolar has launched a new series of ultra-efficient Tiger Neo Modules. The New module adopts N-type TOPCon technology with further enhancements in performance, power, energy density, and reliability. The new module delivers a maximum power output of up to 620W into mass production, with an ultra-high efficiency of up to 22.30%.

Problem: The solar cell efficiency of PERC is approaching its limits of 24.5%, and new cell technology is needed to bring breakthroughs in conversion efficiency, power output and LCOE. With higher efficiency, higher bifacial factor, lower degradation, lower working temperatures and better low-irradiance performance, n-type TOPCon technology is touted to be the next-generation mainstream technology after mono PERC.

Solution: JinkoSolar adheres to a philosophy of high power and high efficiency, and the company is to enhance module power and efficiency by integrating n-type TOPCon technology, M10 (182mm) silicon wafers, 78-cell specification, multiple busbars, and stitch welding technologies. The Tiger Neo module has an ultra-high efficiency of up to 22.30%, a bifacial factor of up to 85% compared with ~70% for p-type, and a lower temperature coefficient of -0.30%/º compared with -0.35%/º for p-type. Thanks to reduced LID and LeTID risk, JinkoSolar provides a 30-year linear power output warranty, with first-year degradation of less than 1% and power output is guaranteed to be no less than 87.40% of the nominal power output after 30 years.

Applications: Large-scale utility, industrial and commercial distributed generation, and residential PV applications.

Platform: The Tiger Neo monofacial module measures 2465mm*1134mm*35mm and weighs 30.6kg in the 156 half-cut monocrystalline cell configuration, with module power range of 595~615W.

Availability: Mass production starts from Q1 2022.

Trackers | Soltec's SFOne 1P and SF7 2P trackers delivering on mechanical simplicity

Product outline: Designed for larger 72- and 78-cell modules, the SFOne is self-powered thanks to a dedicated module which results in a lower cost-operational power supply. Its innovative fully-wireless system and tracker monitoring process is incorporated for full PV plant control, full-safe redundancy and flexible gateway communication offers the lowest latency on the market.

The SF7 2P tracker offers high yield-per-acre performance and superior land-use options. It counts on a complete module-fill, offers asymmetric backtracking and is bifacial optimised, capable of offering a 5% advantage in yield density over gap trackers. The SF7 also has a steep-slope tolerance to 17% grade NS and short-steps tolerance to <48 meters.

Problem: Utility-scale solar system designers and developers are having to make choices between tracker configurations, deciding between 1P and 2P based on the characteristics of the land and location on the project. This is a complicated task and is analysed by professionals in the sector, with project yields and failure or breakdown rates depending on the correct configuration.

Solution: Analysing parameters including terrain and layout is key to choosing between 1P and 2P configurations, and it is important to assess all the parameters that influence this decision. The cost of maintenance and cleaning of modules in operation is also a factor. This requires analysis of the characteristics of not just the project, but of each solar tracker. This allows for an optimised layout to be decided upon, saving time in installation and maintenance and to guarantee the efficiency of the solar project during its operational lifetime.

Application: Utility-scale solar PV projects using trackers.

Platform: The SFOne has an innovative open thread mesh network which uses a fully wireless system, is Internet of Things-enabled and has a tracker monitoring system incorporated for full PV plant control. It includes a string runner to manage the PV source cabling and is easier and faster to install than other trackers. O&M of the project is also easier and faster thanks to a face-2-face position which helps washing vehicles cover twice the array area per vehicle pass.

The SF7 requires 46% fewer piles per megawatt deployed and has 15% less parts compared to other trackers on the market, offering fewer screw connections per pile. Each module can be installed in a short time-frame, reducing construction time and labour costs. The trackerfill results in complete tracker module fill by eliminating array gaps over the pile mounting locations, allowing the SF7 to deliver an increase of up to 5% of megawatt deployed per acre. Both the SF7 and SFOne trackers can include Dy-WIND methodology to combat the affects of high winds and use diffuse booster optimisation for low-light conditions.

Availability: Available now.

How AI can help grids accommodate more solar PV

Technology | Accurate generation modelling and forecasting is integral to not just the financial performance of operational solar farms, but how they are integrated into modern grids. A study from Monash University in Australia has proven how artificial intelligence approaches can help drastically improve performance forecasts. Dr. Christoph Bergmeir, who led that study, details its key learnings.

Credit: Clean Energy Finance Corporation.

The Ross River Solar Farm (pictured) was used in the study.

Predicting short-term energy generation is not an easy task. Renewable energy cannot be produced on demand, as it is bound to natural resources such as the wind and sun. Therefore, to achieve a stable network and enough power generation, we need a reliable short-term prediction method. In a cross-collaborative research project led by myself from the side of Monash University, Australia, I worked with Worley and Palisade Investment Partners to carry out the necessary trials to solidify more accurate 'five-minute ahead' self-forecasting tools.

The project, which began back in October 2018, was funded by the Australian Renewable Energy Association (ARENA) with a budget of almost AU$1 million. The importance of this project cannot be understated, as by improving the accuracy of five-minute ahead forecasts required by the national electricity market (NEM), the generation forecasting solutions developed by the Worley and Monash team can enable a more secure and reliable grid.

The forecasting models developed are based on machine learning algorithms drawing on internal supervisory control and data acquisition (SCADA) data feeds from the generators as inputs to the model. The 130.8MW Waterloo Wind Farm (WWF) in South Australia and the 116MW Ross River Solar Farm (RRSF) in Queensland were chosen for the study. The key benefits of the project include increased renewable energy penetration in the grid due to improved dispatchability of renewable generation and reduction in Frequency Control Ancillary Services (FCAS) payments by generators resulting from the failure to meet forecast targets.

A history of inaccurate predictions

The challenge that my team and I were presented with spawned from a history of inaccurate power predictions, which in 2020 alone cost Australian generators AU$210 million. This stems from the fact that natural weather variations can make it difficult for renewable generators to accurately forecast their short-term power generation levels, thus affecting grid stability. Moreover, using machine learning algorithms to see as little as five minutes into the future is extremely valuable.

Our forecasting algorithms attained a 45% improvement in our partners' power output predictions. This technology has the potential to lower energy prices across the board, and possibly open avenues for other forms of clean energy. If renewable generators can lower their causer pays factors (CPF), they can produce electricity cheaper, and eventually that saving could be passed on to the customers. It would also make renewables more competitive.

The machine learning algorithms for both farms are setup to run as an ensemble and deal with the challenges associated with missing data when there are AEMO (Australian Energy Market Operator) imposed curtailment constraints on generation output. During normal operation the model runs using 30 minutes of past historical SCADA data and active power data. When constraints are active, past values of active power are not available to produce a forecast, so the algorithm utilises lags of possible power and other SCADA variables. The third scenario occurs when the generator is coming out of a constraint, but a full 30 minutes of unconstrained history is not yet available. In this instance the algorithm utilises a model with a smaller historical window that also considers ramping immediately after a constraint is lifted. Finally, each model is independently optimised for Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) with the algorithm combining the two together. The combination of these different models running in parallel means that our algorithm can respond more accurately when constraints are active and lifted by switching between models.

AU$210 million

The cost to Australian generators from inaccurate power predictions in 2020

Whilst the AEMO self-forecast is theoretically described as a five-minute ahead

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forecast, it should more accurately be described as a six-minute and 10-second ahead forecast, as the forecasts must be submitted 70 seconds before the five-minute gate closure time. The forecast horizon also needs to consider the delays associated with receiving the data, processing the model and communicating with the AEMO Application Programming Interface (API); approximately 10 seconds. Since minutely data are used, the models were trained to forecast six minutes and seven minutes into the future, then interpolate the forecasts to obtain a six-minute and 20-second ahead forecast.

Each of the forecasting models has been designed to run at the edge on a Dell Edge 5100 Gateway. The edge gateways are combined with the onsite SCADA systems to feed live streaming data over Modbus protocol into the machine learning models. The Edge devices provide local buffering of data and by not transmitting large volumes of live data, the bandwidth needs for internet communication are reduced. It also means the models will continue to run if internet connection is interrupted and stops for any reason, providing a seamless recovery once communications are re-established. Connection to the AEMO API, remote monitoring of model performance as well as patches and updates to the model and edge firmware are all enabled over internet connection.

Inside the results

When looking at the results of the Waterloo Wind Farm performance, 16,123 five-minute dispatch intervals were evaluated over the assessment period. Out of those, 1,442 were constrained and 14,681 were unconstrained. During the valuation period, our algorithm successfully outperformed the benchmark AWEFS (ANEMOS) forecasts. Moreover, our algorithm showed an average improvement of 19.8% on MAE and 45.6% on RMSE during unconstrained periods.

Moving onto the performance of the Ross River Solar Farm, 10,423 five-minute dispatch intervals were evaluated over the valuation period. Out of those, 259 were constrained and 10,164 were unconstrained. During the assessment period, our algorithm successfully outperformed the benchmark ASEFS (ANEMOS) forecasts. Our algorithm showed an average enhancement of 2% on MAE and 8% on RMSE during unconstrained periods.

Whilst numbers and statistics help us define the success of these trials and our research, it is wise to look at the financial benefits of the five-minute ahead forecasting method, as this is where we can provide real value to businesses and consumers alike. As both RRSF and WWF have existing self-service forecasting providers and do not use the ANEMOS forecast algorithms, it was not possible to benchmark the commercial benefits of our self-forecasting algorithm versus ANEMOS at these sites.

To work out the commercial benefits, historical regulation FCAS charges are divided by total generation capacity to determine an approximate cost per MW/year. Regulation FCAS has historically exhibited extreme volatility. Based on this approach, annualised savings are estimated between AU$45,000 to AU$100,000 per year for the wind power forecasting algorithm, and AU$5,000 to AU$20,000 for the solar power forecasting algorithm under 'normal' FCAS price ranges. Savings could easily surpass these estimates, particularly during extreme pricing events such as the South Australia separation incident in late January 2020 where even minor improvements in CPF would yield disproportionately large savings.

> "Savings could easily surpass these estimates, particularly during extreme pricing events such as the South Australia separation incident in late January 2020"

One of the features of our wind forecasting algorithm is that it is far less prone to over prediction (Kurtosis and Skewness) than the ANEMOS forecasts. High Kurtosis is a measure of the weight of the tails in the error distribution. The high Kurtosis for the ANEMOS forecast means that it is more likely to deliver high forecasting errors than our self-forecasting model. The Skewness of the distribution shows the bias of the distribution towards over or under prediction.

Our model is neutrally biased with a Skewness very close to zero. The ANEMOS forecast is heavily negatively biased, meaning that it is more likely to over predict the generation output than under-predict. The benefits of this behaviour are significant but difficult to estimate. Because the CPF calculation sums the deviations over the dispatch period, extreme outliers will inflate the net deviation calculation and therefore attract a higher CPF. As a result, the actual benefits to wind farms may be meaningfully underestimated.

Who benefits?

The benefits of our research and forecasting methods to grids, the market and consumers are plentiful. The objective of regulation frequency control is to achieve generation and demand balance in response to minor deviations in load or generation. Imbalance results in frequency rises or falls which, if not addressed, can compromise overall stability of the system. The FCAS market is the mechanism that AEMO uses to alter the generation and load balance to maintain frequency stability. With the introduction of self-forecasting, semi-scheduled generators can set their own five-minute dispatch targets.

The forecasting algorithms established for this project have demonstrated an ability to out-perform the AEMO AWEF and ASEF forecasting models which would result in a lower CPF for individual generators. If these improvements were extrapolated across all solar and wind farms in the NEM, the cost of regulating FCAS services across the market as a whole would reduce, making renewable energy projects more attractive to investors and driving down the cost of energy for consumers.

The results from this project have demonstrated that improvements can be made to forecasting accuracy for both wind and solar generators by employing best practice machine learning techniques. The results from the wind farm were particularly positive, with significant improvements in both RMSE and MAE. The wind model also displayed a robust ability to maintain accurate predictions even during ramping events, such as after constraints were lifted. The objective of this project was to explore methods for self-forecasting that could develop a more accurate five-minute ahead forecast, which has been achieved. ■

Author

Dr. Christoph Bergmeir is a senior lecturer in Data Science and Artificial Intelligence, and a 2019 ARC DECRA Fellow in the Department of Data Science and Artificial Intelligence at Monash University, Australia. His fellowship is on the development of "efficient and effective analytics for real-world time series forecasting". He works as a Data Scientist in a variety of projects with external partners in diverse sectors, such as in healthcare or infrastructure maintenance.

What transmission technologies are easing grid connection?

Grids | New technologies are emerging to help constrained grids integrate an increasing number of solar projects. Molly Lempriere takes a look at three case studies of where technology is helping to decarbonise the grid faster.

Solar power has surged around the world in recent years, driven by the steep decrease in the cost of the technology and the increasing number of countries looking to decarbonise their energy networks. But whilst solar is often celebrated for its ease of installation, a grid connection can often be where projects struggle.

Connection delays in countries like Australia, Spain and the UK have caused investment and development challenges for solar, as aging infrastructure struggles to keep up with diversified and distributed generation.

But a number of new technologies are being developed to ease this congestion, including Point of Connection Mast connections, Renewable Energy Zones and a new strategy for substations.

How POC-MAST enables solar farms to connect to the grid

By Martin Buckland, managing director, Freedom Professional Services

Getting their projects connected into the electricity distribution network can be a challenge for solar developers, as network operators work to expand alongside the booming renewables sector. To ease this, many are looking to innovative new technologies as an alternative to often costly traditional connections.

The Point of Connection Mast (POC-MAST) is a revolutionary way of making the connection process for generation or load projects faster, safer and cost-effective. Suitable for connecting to overhead lines up to 132kV, POC-MAST can connect to either tension or suspension towers and is revolutionising the way new connections are delivered.

POC-MAST was first developed by Freedom, an NG Bailey Group company, as a bespoke solution for a renewable energy project where a traditional connection wasn't possible. It quickly became clear that this solution overcame many common barriers associated with traditional connections and provided a range of benefits to both developers and distribution network operators (DNOs).


Credit: Freedom Professional Services

POC-MAST technology is connected to overhead lines of up to 132kV.

DNOs in the UK have an obligation to provide new customers with a connection as quickly as possible and must balance providing a timely service with ensuring minimal disruption to existing customers. Due to the significant disruption new connections can cause, these installations are often only able to be carried out during British Summer Time when demand on the network is lower, meaning projects cannot be connected on demand. Furthermore, the longer it takes for customers to get connected, the more potential revenue they lose while they wait for their projects to go live.

DNOs have seen requests for connections onto their networks increasing dramatically from a few a year to dozens a month, putting pressure on them to deliver faster connections, more frequently.

Designed to meet the technical advancements of the generation, load and battery storage markets, a key advantage of POC-MAST over traditional connections is that there is no requirement to cable back to the nearest substation or to build a new overhead line tower, which in turn speeds up the overall connection process.

POC-MAST, which is assembled on the ground, can eliminate the need to construct a new tower and temporary diversion tower when delivering new connections. As most of the work is carried out at ground level, the safety risks of working at height are eliminated. The number of times the network needs to be de-energised and the reduced construction scope associated with the POC-MAST installation saves time, reduces costs and minimises the health and safety risks – all of which make a positive difference to whether a connection scheme is viable.

The product also minimises the environmental impact of new connections. The screw anchor foundations remove the need for deep excavations and can save up to 30 tonnes of concrete on a project.

The first POC-MAST installation was for a new solar farm in the UK, which required connecting to a nearby 33kV overhead line tower in DNO UK Power Networks' region – which covers South East England, East of England and London. The overhead line tower, which was built in the 1940s, had an unusual configuration which meant alterations to the existing tower steelwork would have been problematic.

After undertaking a detailed study of the existing tower, the first POC-MAST was commissioned and produced. It provided a safe, cost-effective solution. Although this was the first time this solution was used, the design and installation were safely delivered on time and to budget.

More recently, Freedom has installed a POC-MAST for a 70MW solar farm for Scottish and Southern Electricity Network (SSEN). The 213-acre solar farm at the former RAF Lyneham base in Wiltshire had been developed by SSEN with the UK's Ministry of Defence. The location, next to an ancient woodland, presented several challenges and it initially appeared that the permanent connection would require the installation of a new pylon, diversion of an overhead line and removal of part of the woodland. The POC-MAST installation enabled a connection directly onto an existing tower without the need to disturb any of the surrounding woodland.

Each of the two POC-MASTs required for the looped connection were lifted into place in just six minutes, and the total installation took 10 working days. A new tower and diversion would have taken longer, required multiple outages on both circuits and cost significantly more.

POC-MASTs have also been installed at other locations with much success. The feedback has been positive with the engineering solution bringing flexibility to the renewables grid connection. The flexibility to connect generators using a relatively lighter structure at a fraction of the time needed to connect using existing solutions is undoubtedly helping DNOs optimise utilisation of their infrastructure.

Credit: NSW Government.

Renewable Energy Zones are bringing forward gigawatts worth of renewables connection applications.

NSW Renewable Energy Zones help overcome grid congestion challenge

By a spokesperson for the Department of Planning, Industry and Environment of the Government of New South Wales

Over the next decade, the energy sector in New South Wales (NSW) will be transformed at an unprecedented scale. Renewable Energy Zones (REZ) are modern day power stations that bring together renewables with storage and network infrastructure in a coordinated way to deliver cheap, clean and reliable electricity to homes and businesses.

REZ are one of our best options to replace retiring coal-fired power stations due to the plummeting cost of renewable energy, advances in storage and firming, and the abundance of renewable energy resources that regional NSW has at its disposal. By connecting multiple renewable generators and storage in the same location, REZ capitalise on economies of scale, unlocking new energy sources at a lower cost.

The NSW Government, with its new statutory authority the Energy Corporation of NSW (EnergyCo NSW), is coordinating the development of five REZ in the Central West-Orana, New England, South-West, Hunter-Central Coast and Illawarra regions.

It's critical we act now, since four out of five of the state's coal-fired power stations are scheduled to retire within the next 15 years, starting in 2023. These power stations currently provide around three quarters of the state's annual generation and if not replaced prior to closure, consumers will face significant price hikes.

We must also urgently upgrade network infrastructure to allow new generation to connect to the grid. To put the scale of this task in perspective, existing generation and transmission took 30 years to plan and build and now we have to replace it in half the time. The expected build time for each REZ can take up to ten years and each pumped hydro project needs up to eight years to develop.

A coordinated and planned approach, central to delivering these REZs, will help address two main challenges currently impeding investment in NSW, and help unlock the scale of private investment needed to support this energy transformation.

The first challenge is lack of capacity in the network. Many of NSW's prospective renewable resources are located in parts of the state where grid capacity is low, making it difficult for investors to commit to build new energy generation and storage. At the same time, network companies cannot be certain they will recover the full cost of network upgrades to enable new energy generation and storage projects to connect, unless these projects are committed to be built.

The NSW Government's Electricity Infrastructure Roadmap aims to solve this 'chicken and egg' problem by introducing provisions for authorising the construction of network infrastructure while ensuring electricity consumers only pay the efficient costs of these upgrades.

Proposed reforms will establish a bespoke NSW regime, a Transmission Efficiency Test, similar to the regulatory investment test for transmission (RIT-T)

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and National Electricity Rules cost recovery provisions for REZ network infrastructure projects, to allow scale-efficient network investments to proceed.

The second investment challenge the Roadmap is solving, is that access to the grid is not currently coordinated or controlled in a way that encourages investment. This means early movers may eventually have their projects curtailed or congested as further projects connect to the network. This 'free rider' risk creates a disincentive for investments in network upgrades and increases the upfront costs of capital.

To address this, the Roadmap will deliver access schemes to govern which generation and storage projects can connect to specified network infrastructure in the REZ and how they may use that infrastructure.

It is proposed that, under an access scheme, access to the REZ network infrastructure will be allocated through a competitive process. This will include planning the connection of energy generation and storage projects to optimise the utilisation of the REZ infrastructure and help ensure that infrastructure minimises impacts on, and delivers benefits to, local communities.

Generators would pay an access fee to connect to the REZ, which would include a component to support community and employment initiatives.

EnergyCo NSW is also investigating potential innovative network infrastructure solutions, such as technology solutions, that could optimise the performance of the REZ by increasing export capacity, complementing proposed network augmentation, improving network resilience or providing additional system strength.

For each REZ, we are following a thorough, engagement-led and evidence-based process.

We are ensuring they are supported by communities and industry and will complement the Australian Energy Market Operator's Integrated Systems Plan, other NSW REZ and the objectives of the broader Roadmap.

While each REZ will be developed differently to reflect each area's unique opportunities and challenges, EnergyCo NSW will follow the principles of early and open engagement with all stakeholders and the community.

Despite the immense scale of the challenge, we are already making significant progress.

Recent industry Registrations of Interest processes undertaken for the Central-West Orana REZ and New England REZ received an overwhelming response from investors, with proposed projects totalling nine times and four times the intended network capacity required for each REZ, respectively.

The transformation has begun, and we are on track to reach our ultimate goal for NSW to enjoy some of the cheapest, most reliable and cleanest energy in the world by 2030.

Developing regional 'hubs' to solve infrastructure challenges

By Steve Serpant and David Williams, directors, Gridmode

The UK has been among the first countries to set a legally binding target of net zero by 2050 and has aspirations to decarbonise its power system by 2035. The Net Zero Strategy, published on 19 October 2021 by the Department for Business, Energy and Industrial Strategy, binds us to building a secure, home-grown energy sector, with a reduced reliance on fossil fuels and exposure to global wholesale energy prices.

Not only do we need to rapidly increase power production from self-sufficient sources, such as solar and wind to achieve this, but also – as we are heavily reliant on gas to produce electricity utilising synchronous power generators – we require a large programme of conversion or replacement.

The UK needs to quickly shift to renewable sources for its electricity production whilst balancing the intermittent nature of power generated using wind or solar. At present, balancing is partly carried out by gas (or even coal) fired power generation to support demand. Some batteries are employed in this, but there is a need to increase battery infrastructure on the grid many fold.

As we've seen in recent months we need to protect the UK from gas price increases, so reducing our gas 'fleet' is key. This leaves a huge gap in the power generation needed to meet our increasing demand, particularly so with the growth of electric vehicles. In addition, the current status of importing energy from other countries exposes us to a huge shortfall of low-price energy.

Gridmode is an energy infrastructure start-up, born from solar project development established to design and develop 'hubs' that solve specific regional grid infrastructure issues, in turn unlocking renewable connection capacity on a large scale.

Whilst developing utility-scale solar projects in the UK, Gridmove – the renewables development arm of Gridmode – was forced to connect to the UK's transmission grid because the regional distribution network operator (DNO) was unable to accommodate such a development. This is a common theme across the UK presently and a real issue when considering the UK's net zero ambitions.

A strategy of unlocking further sites was put into motion, something more holistic than one incorporating just solar PV or battery energy storage systems. No single technology was deemed capable of resolving specific grid issues or power flows, and instead new ways were considered as an alternative to traditional grid infrastructure asset ownership.

To date, Gridmode has implemented a strategy designed to help ease grid-level constraints and then address capacity connection issues across the UK. The strategy works by targeting restricted areas of the country's electricity networks – identified via the company's experience as a developer, coupled alongside known development of new generation – and then unlocking megawatts of spare capacity per site. Specific constraints are identified through a site-specific connection study, which isolates what is likely to have caused or continues to cause the constraint on the network. Specific connection strategies are then determined to ease constraints and unlock capacity.

Collectively, and through the rollout of a proposed £1 billion capital programme to invest in a private network of 400kV substations, it's estimated that as much as 8GW of new renewable energy capacity could be unlocked over the next decade. More than 30 400kV substations are planned for throughout the UK, with development aimed to commence in early 2023. Independent specialists including TLT Solicitors and market research firm Cornwall Insight have been engaged in the project.

Moreover, the scheme would also create around 3GW of battery energy storage infrastructure connected to the UK's transmission grid, which would then be able to provide services to further support the migration to non-synchronous power generation, such as inertia. ■

Climate-specific O&M for PV power plants

O&M | As solar finds itself deployed in more exotic climes, it is also having to operate in increasingly harsher environments. Ulrike Jahn of VDE Renewables and Dr. Bert Herteleer of KU Leuven assess how such climates affect PV performance and what must be taken into consideration when formulating O&M strategies.

Solar photovoltaic (PV) plants are complex systems, despite being composed of modular equipment that appears simple at face value. The final products such as PV modules, power conversion equipment (inverters, transformers, combiner boxes, etc.), module mounting structure, etc., are installed onsite and the PV plant, together with all the equipment, are then commissioned into operation of a lifetime typically of 25 to 30 years.

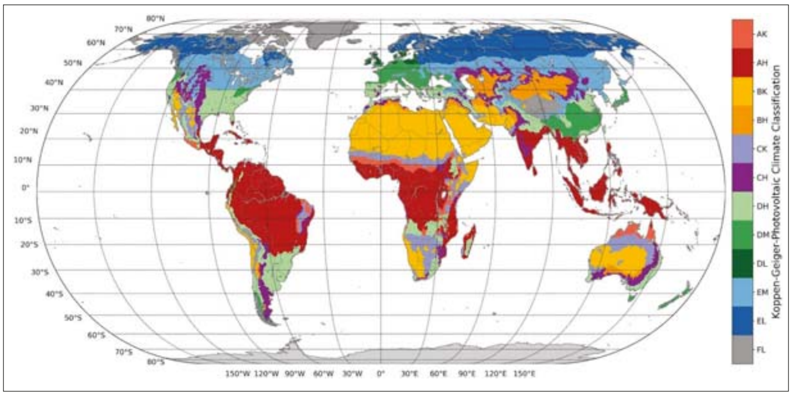
The performance and durability of the different PV plant components varies over the lifetime of a PV plant, and consequently the operation and maintenance (O&M) efforts.

It is obvious that the climatic environment in which the equipment operates will influence the equipment's rate of aging defect growth, failure progression or degradation; as different materials respond differently to different climatic stress factors such as temperature, humidity, UV light, rain, wind, etc. A combination of these climatic parameters will also create second-order stressors, such as mechanical load from snow or soiling from dust to PV power plants.

Typically, PV plant operators offer a rather standard (O&M) scope of services that could be replicated easily across to reach an optimal point between minimising O&M efforts (and therefore expenditures) while maximising PV plant uptime, performance and durability. However, a shift from the one-size-fits-all approach to a customised O&M approach could offer an advantage that the O&M activities are adapted for the needs of the PV plant, focusing on what maintenance activities are necessary for that specific plant.

Such customisation could be setting an O&M service based on the climate zone in which a PV plant is located. Figure 1 shows a new approach of the Köppen-Geiger PV map [1], which provides classification and implications to worldwide mapping of PV system performance with respect to temperature, annual insolation and precipitation.

Photovoltaic climate classification and implications to worldwide mapping of PV system performance [1]



Credit: Dr. J.Ascencio-Vásquez

One of the main challenges in customisation of an O&M strategy for a specific climate zone at present is the lack of comprehensive guidelines for O&M providers. Existing guidelines and standards do not fill the gaps or clarify the minimum requirements of climate-specific O&M and their implementation. In this paper, we aim to provide comprehensive guidance on setting up a customised O&M practice for PV plants located in three different climate zones: moderate, hot and dry as well as in flood-prone (monsoon) climates.

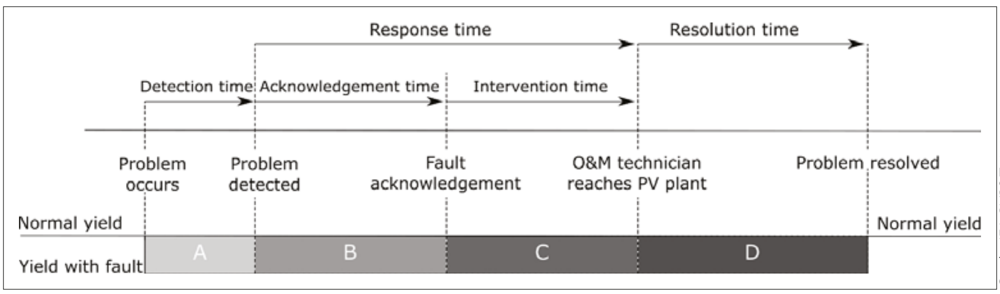
While the first two refer to general climate zones, the last one is more specific to extreme weather conditions. The recommendations for an optimal and appropriate O&M strategy for PV plants in specific climates are prepared based on real field experiences of experts from various countries representing the climate zones addressed [2].

Rapid response

There are different key performance indicators (KPIs) for O&M contracts of PV power plants, and they are tied directly to the performance of the PV plant such as the performance ratio (PR) and the plant availability, or the maintenance services performed.

The response time is an O&M KPI that is based on the maintenance service performed. Some O&M operators may opt to guarantee maintenance response time to faults/alarm events. This is usually expressed in minimum time intervals (in time units such as minutes or hours) to trigger an intervention and is timed from the moment the event or fault occurs. In this approach, the response time should be

Stages from fault to resolution



Credit: IEA-PVPS T13-25:2021

categorised into responses to critical, major, and non-critical events. Faults or events with immediate impacts on the safety operation of the PV plant, such as a fire event, are critical and require immediate intervention. Faults or events with major impacts on the plant production, such as inverter shutdowns, require a response within a day or two from the alarm trigger.

Figure 2 shows the O&M KPIs relating to response and resolution time, and the associated yield losses for each phase. In many cases, the detection time will be very short, although this depends on the nature of the SCADA system and the type of fault. Depending on the contractual framework, the yield lost (the areas indicated by the letters A to D) may be excluded or not from KPI shortfalls and penalties.

- **Detection time:** depends on type of fault, monitoring software (difference between ((rapid)) degradation, shading, inverter issues, etc).
- **Acknowledgement time:** depends on detection mechanism and awareness/ action by O&M provider
- **Intervention time:** Time taken for O&M personnel to mobilise onto site. Depending on system scale and remoteness, this is nil (for staff based on site) to days or even weeks for remote/hard-to-reach systems.
- **Resolution time:** Once the issue has been properly diagnosed and a solution determined and agreed upon with the asset owner (if applicable), resolution time can be short (hours-days) to long (days-weeks) to very long (months). Here, spare parts management by the O&M provider and the risk (and cost) appetite by the asset manager play an important role.

Digitalisation will enable the creation of BIM/Digital Twin concepts which will allow an asset to be properly followed along the whole value chain down to component level, from the manufacturing phase, through engineering, procurement and construction (EPC), O&M and end of life. The development of data-driven and/ or physical models (reliability models of PV modules, inverters and other BOS components) will enable predictions of the lifetime based on field data including climate dependent stress factors, which then feeds into data-driven O&M strategies. Despite the rapid professionalisation of the PV industry, data-driven O&M strategies are still in their relative infancy and require further work.

Recent evolutions in contracts for O&M have seen the KPIs change from PR or energy-based values to service time values: response and acknowledgement time. This reflects the growing awareness that the O&M provider needs to be evaluated on aspects which are (easily) measurable, and that the performance of the PV system was determined in the design and installation phases. From this revised view, the O&M provider is tasked with ensuring that the PV system can operate to the best of its capabilities as they have been received/ inherited from the previous responsible party (EPC, or O&M provider), ensuring that inverters are online, that PV module trackers operate within specifications and so on.

Yet the O&M provider is not responsible for the behaviour of PV modules and inverters under weather and operational constraints. It should be clear that the best and most nuanced approximation of the true health of the PV power plant, as well as how well the O&M contractor is performing, are obtained through the judicious application of multiple KPIs.

A key tool to minimise or eliminate risks is the hierarchy of controls methodology, as shown in Figure 3. At the O&M stage, the ability to eliminate risks is limited compared to the design and construction phases (where safety can be designed into (or omitted in the design of) the PV plant) unless additional investments are performed. The O&M operator will have most control of risks from engineering and administrative controls as well as the appropriate use of personal protective equipment (PPE), while elimination and substitution of risks are typically part of the plant design.

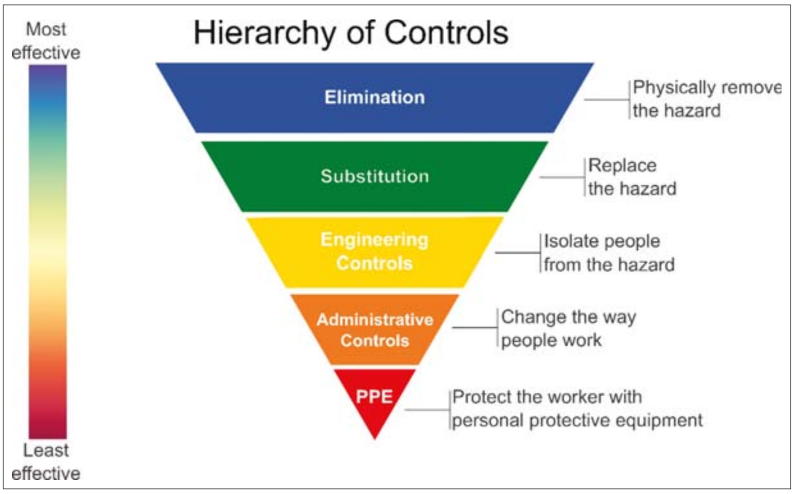
O&M in moderate climates

The O&M guidelines for moderate climates cover the basic or most common aspects and conditions that are common to different climates or regions. More extreme climates have different specificities and may require more attention for operators and strategies for maintenance.

Moderate climates are very well suited for the development of vegetation and wildlife throughout the year, so that the seasonal changes are smooth enough for the survival of many species. Although this may seem contradictory today, the development of nature near PV modules, inverters, etc. is not always welcome.

Among other things, vegetation and wildlife can become a problem during certain periods of the year, affecting energy yields. In temperate climates, soiled PV modules often contain bird droppings, agricultural emissions, pollen, lichen and traffic residues, such as engine exhaust, and show strong seasonal variations. With frequent rainfall, most of the pollution is washed off, but there are conditions, especially during a dry period or heavy agricultural activity, where the pollution rate - the comparison between clean and dirty - can vary by several percent.

There are several methods to contain soiling - preventive and restorative - such as manual, semi-automatic or fully automatic cleaning solutions. Fully automated, pre-installed solutions with very low water consumption or even dry brushing are attractive for large facilities in regions with a very high risk of soiling. On the other hand, semi-automatic or manual cleaning systems using demineralised water or some biodegradable chemicals to wash off organic matter might be more cost-effective in temperate climates. There is no one-size-fits-all solution for mitigating pollution impacts. It is a local economic decision based on labour costs, availability and cost of water, feed-in tariffs and medium-term weather forecasting.



Credit: National Institute for Occupational Safety and Health

The hierarchy of controls for risk mitigation, with broad engineering applicability. In light of the covid-19 pandemic, our awareness of the use of PPE (face masks) and elimination of risks (working from home, lockdowns) has increased. Based on [2].

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Japan	Report on Guidelines for Periodic Inspection and Failure Examination of PV Power Systems	Japan Electrical Safety & Environment Technology Laboratories
United States	Best Practices for Operation and Maintenance of Photovoltaic and Energy Storage Systems; 3rd Edition	National Renewable Energy Laboratory and others

Available O&M guidelines for PV power plants in different parts of the world [3].

Bird droppings are the biggest problem for yield when it comes to soiling of PV modules in temperate climates. It is important to create a cleaning schedule based on the frequency of bird droppings, which is highly dependent on the type of birds that live in the area and pass through it on their migration route. This planning should prevent drops from sticking to the module glass for a long time for the following main reasons:

- Loss of energy output.
- Hot spots leading to material deterioration and increased electrical risk.
- Etching effect on the glass, leaving a non-removable mark on the surface.

It is important to be aware of the risk of various chemical products that can be harmful to the glass, the glass coating and the frames of the PV modules. They can put both the module and the product warranty at risk.

For rodents, it is recommended to secure cable loops and hanging cables as far as possible from the ground or from structures that can easily be climbed. If more protection is required, solutions are available on the market to protect against rodents, such as cable shields.

Most animals living near PV ground-mounted modules are livestock such as grazing sheep. They can control the vegetation in PV installations and usually do not climb on or damage the PV modules. The first row of modules may be exposed to them, which could be pushed by their bodies when they reach the growing grass under the PV modules. In general, it is worth mentioning that both the PV modules and the structures are a good opportunity for them to scratch their skin if necessary. It is recommended to check the mechanical condition of the structure and the first row of modules regularly.

For insects, the cool shade under a PV panel and the empty interiors of metal structures are often ideal for building wasp or bee nests. In the case of metal structures, plugging the holes can prevent a nest from being built inside. On the back of PV modules, nests tend to become entrenched in frames and cables, making maintenance difficult.

Cutting or spraying with herbicide is the common method of controlling vegetation. The herbicide should be applied in an appropriate manner without spraying the PV modules. After a few days, when the vegetation has died, it should be pulled out by the roots and the waste treated accordingly.

In relation to occupational safety and health, international standards and national codes are an important reference (Table [1]). Public guidelines developed by industry, research or national institutions are also a good source of summarised and detailed information, as listed in Table 1.

O&M in hot & dry climates

In hot and dry climates (Köppen-Geiger PV classification: BK) there are high summer ambient temperatures (often reaching 40°C / 104°F) and very little precipitation. Typically, precipitation comes in the form of heavy downpours, with little or no rainfall for much of the year.

The combination of physical remoteness and challenging climatic conditions results in a strong preference for remote monitoring of PV plants, with few plants having O&M staff on-site or nearby. This is reflected in the O&M KPIs, where availability values of less than 99% are occasionally observed.

The greatest risks for maintenance staff working on PV systems installed in these regions arise from the high temperatures and high irradiance (with high UV content) that can routinely occur. Therefore, site visits typically need to be scheduled in the early morning hours, often with two or more workers for mutual support and back-up. Similarly, if modules are cleaned with water, the cleaning work must also take place in the (early) morning hours to avoid temperature shocks and glass breakages. Occupational Health and Safety (OHS) requirements dictate the use of appropriate PPE, which must also provide protection against sunburn and heat stroke.

In addition, heat (stress) management and mitigation plans are required to ensure that staff are adequately hydrated and can take a break from the heat. The potential presence of venomous insects and animals also needs to be considered in O&M procedures, such as identifying actions to take in the event of snakebites, e.g. providing antivenom near the PV system, or having wildlife specialists on call to remove venomous snakes from the property.

Regarding the hardware, birds, termites and ants can build their nests near PV modules and inverters, which can lead to fires or short-circuits. Cable ducts should be sealed, and electrical cabinets must be inspected at regular intervals, as termites and other pests can travel towards inverters or cabinets, and extra care must be taken when opening the cabinets.

Travelling to remote PV sites is an underestimated risk by many O&M contractors: stray livestock and other large animals can be encountered during the trip, as can the possibility of flash floods making roads impassable for hours and ensuring that a (charged!) satellite phone, first aid kit and sufficient water for both the car and the passengers are available before the trip can be forgotten for "routine" work. Preparation, communication and logging of travel plans, and O&M activities is therefore of great importance.

When vegetation is present, soiling of PV modules is usually less of a problem in hot and dry climates; instead, yield losses due to rapid crop growth after rain events are possible. In these areas, vegetation management is also implemented together with fire breaks (physical barriers that impede the spread of bushfires, such as cleared roads at the edges of PV plants) to facilitate access to the PV arrays. Vegetation management is often reactive, i.e. following rapid vegetation growth after rainfall events, and the contracts often reflect these reactive activities. Due to the relative remoteness of such

Credit: Dr. Bert Herteleer

Vegetation management (photo left) is required to reduce fire and wildlife risks and improve access to arrays, yet the activity itself entails risk to modules (photo right: broken glass due to stones flying against the module). Photographs of PV systems in Central Australia.

PV sites and their impact on the system maintainability, combined with relatively low pollution losses, the use of automatic soiling management systems (e.g. cleaning robots) has been limited to date.

In hot and dry climates without vegetation, on the other hand, soiling losses are usually higher, and therefore the need for automated module cleaning solutions has increased. The difficulty and higher cost of obtaining water (and occasionally, with high mineral content, which can leave mineral deposits such as calcified film on the module glass) have led to a preference for low-water or no-water solutions for module cleaning, such as fully automated dry brushing.

O&M in flood-prone (monsoon) climates

In theory, for easiest O&M and overall lowest cost, PV power plants should be installed in areas that are easily maintained with low weather and climate risks. However, in many countries, social license requirements force PV systems to be built on land unsuitable for agriculture and other commercial activities. Moreover, an underestimation of flooding risk in the development phase, by looking at too short a historical dataset or ignoring changes to the surroundings (such as upstream clearcutting of forests, or newly developed areas), see PV power plants located in areas with high (flash) flooding risks, which is particularly pronounced for areas with monsoon-like climates.

When exposed to floods, PV power plants are subjected to two main types of stressors: fast flowing water and/or impacts with debris, and continuous submergence. The first category often results in (catastrophic) damage that is visible to the eye, whereas the second sees a combination of electricity and water, and unintended/unforeseen current paths, which can cause less obvious damage to infrastructure, requiring specific inspection methods to ascertain the health of the PV power plant (IR, EL, I-V curve measurements, isolation checks).

In this regard, experiences from Kerala, India (Köppen-Geiger PV AH: monsoon climate) are illustrative of the challenges experienced by asset owners and O&M contractors with flooding of PV power plants. In general, (partial) submersion of PV system infrastructure (arrays, cabling, string combiner boxes, inverters, electrical cabinets and transformers) can lead to large, yet unexpected forms of damage or yield loss. Forms of damage range from bent modules, broken or melted module glass, deformed or damaged junction boxes, or even permanent forms of soiling can be seen after flood events, all the way to unexpected current paths resulting in short circuits in string combiner boxes, electrical cabinets, inverters and transformers. It's important to note that, if a system has been (partially) flooded, damage may be present in hardware, regardless of whether it has been submerged, and this can manifest even days or weeks after the flood event.

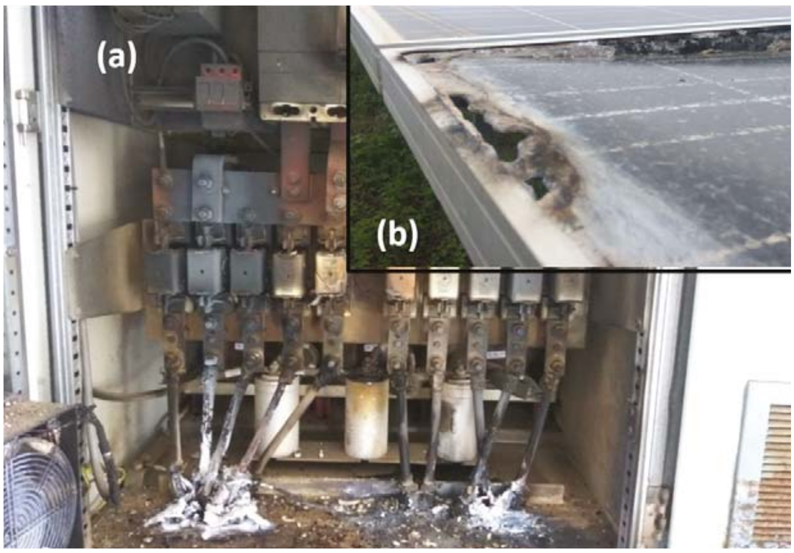
Figure 5 and Figure 6 show the spectacular damage that can occur for PV systems subjected to flooding. Figure 7 shows how some PV systems can be fully submerged for days or weeks.

Depending on the power plant design (e.g. raised inverters, channels to guide flood waters), equipment used (e.g. IP67 or IP68 junction boxes of PV modules), and the extent of the damage, post-flood equipment checks similar to the commissioning of power plants are required to ensure the continued safe operation of the asset.

It should be clear that the magnitude of damage to PV power plants can be so

Credit:Prof.Narendra Shiradkar, Indian Institute of Technology

Damage to modules and structures (a) and structures only (b) due to submersion with fast-flowing waters [3][4]



Credit:Prof.Narendra Shiradkar, Indian Institute of Technology

Consequences of partial submersion of PV systems. Inset photograph b shows burn marks and melted glass of PV modules, even though these modules were not submerged [4].

Credit: Prof Narendra Shiradkar, Indian Institute of Technology

Fully submerged arrays (blue circle) and partially submerged arrays (black circle) [4].

large that evaluation of O&M contractor performance using standard KPIs is not always feasible, instead becoming an insurance matter.

For OHS, the precautionary principle mandates that for O&M activities the entire system should be treated as if it was submerged (with higher risk for staff and hardware), unless there are objective reasons to treat (part of) it as safe. Similarly, snakes, spiders or crocodiles may have been transported to the flooded PV power plant area and due care should be exhibited by staff when performing inspections or remedial work.

Outlook for the future: risk appetite, climate change and incentive structures

As the capital expenditures (Capex) for PV plants has rapidly decreased in the recent years, operational expenditures (Opex) play an increasingly important role in the system's return on investment and the system levelised cost of energy (LCOE), especially, when the lifetime of PV plants exceeds 25 years.

Although PV power plants have relatively low Opex compared to other electricity generation technologies, they still require maintenance to achieve their full potential over their lifetime. Assessing the balance between potentially lower returns (i.e. higher revenue losses) at lower Opex and higher returns at higher Opex is a risk assessment that may need to be reviewed during the life of the plant, to ensure that the risk-return structure is as intended. This raises questions about spare parts management: should critical spare parts be purchased at the beginning of the power plant's life and stored nearby, or are there mechanisms to defer certain purchases to a later stage in the life of a PV system? The risk tolerance of the asset owner will play a role in this decision. Given the supply chain disruption resulting from the Covid-19 pandemic, it is worth re-evaluating whether the spare parts strategy is still fit for the purpose, especially for critical items with long lead times such as inverters in the MW range.

For larger O&M contractors managing a portfolio of PV power plants, it may be worthwhile to centralise the storage and purchase of critical/important spare parts (inverters, PV modules, Ring Main Units (RMUs), etc.), although this depends on how the O&M strategy for individual PV power plants has been designed and the contractual framework for multiple plants. Similarly, evaluating the risk profile of PV power plants in different climates may prove beneficial – the interested reader can consult [3] for best practices for O&M in other climates.

The increased frequency of extreme weather events (EWEs) due to climate change poses a challenge for asset owners and PV plant operators, as the assumption of a constant probability of extreme weather events over the lifetime of the PV system no longer applies, and can lead to catastrophic damage to the system or nearby grid infrastructure. For example, 100-year rain or flood events may occur more frequently than expected/assumed during planning, or hurricane-force winds may damage the modules and their mounting systems. Consequently, the asset owner needs to re-evaluate their risk appetite and the willingness to pay for higher resilience of the PV system (e.g. physical elevation of inverters, installing flood barriers, installing hardware and software to proactively shut down PV plants in case of EWEs).

For O&M providers, preparing for the consequences of EWEs may involve updating procedures for staff safety, proactive weather monitoring (both for staff visits before/after EWEs as well as for the PV plant itself), re-evaluating spare parts supply management and storage locations (having a spare parts warehouse on site can reduce "standard" O&M costs, but may result in additional problems if that site is hit by an EWE, as the spare parts are also likely to become unusable).

One topic that the PV industry needs to work on further concerns incentive structures and attitudes: the contractual framework as currently used in the majority of systems provides an incentive for the O&M provider to try (only) "good enough" efforts, as there is no benefit sharing. Related to this is the binary attitude shown by some asset owners: if return-actual > return-target: take no action, if return-actual < return-target t: contact/penalise O&M provider. In some cases, such as those with greater solar irradiation, the absolute yield increase may be greater than the expected performance loss rate (and thus a happy asset owner), but the health of the PV system may decline faster than anticipated, which is masked by the higher absolute yield. On the other hand, a year with poor insolation can lead to lower absolute yields than expected, even though the PV system is well maintained.

The PV industry is therefore best served if well-informed stakeholders can discuss and evaluate system performance, the objects of which are better aligned with the long-term reliable operation of power plants. Only if plants meet or exceed their expected lifetime and associated yields, facilitated by sound operation and maintenance, will they fulfil their potential for cost-effective low-carbon power generation. ■

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The right time for repowering?

Repowering | As operational solar assets mature, news of repowering projects is steadily ramping up. Alice Grundy takes a look at what's influencing decisions and just when the right time to repower is.

Repowering is perhaps more frequently associated with wind power than solar PV, with there being many wind assets across the globe that have, to put it casually, been there, done that and got the t-shirt. But for many solar PV assets, what was once a far-off, distant prospect is now rapidly approaching and bringing with it a whole new set of financial and technical considerations.

Of course ,there are various markets around the world where solar PV repowering is – if not necessarily common – certainly gathering pace. The likes of Germany and Italy, where the solar market is more mature, have already seen PV repowering to a certain or lesser extent.

The UK hadn't been expected to begin its repowering journey for several years to come, with its PV market a little younger than its European counterparts. However, the first smattering of solar plants are now beginning to repower, with BayWa r.e. recently undertaking the repowering of operational projects for UK solar and battery storage investor Gresham House. So the question then becomes, what's driving those decisions – both in the UK and further afield – and for those hanging back, just when is the right time?

The driving forces behind repowering

The first question that needs to be answered – and perhaps the simplest - is what's the point? While there are some fairly obvious benefits to repowering, some certainly take a little more digging into to get to grips with. But a full understanding of these benefits is key to being able to determine whether they outweigh the financial commitment inevitably involved in a repowering.

Chief in the list is improved revenue. Typically, an asset is repowered either when it is naturally nearing the end of its life or is experiencing a significant amount of down time due equipment that is faulty, degraded or both. As such, repowering allows an asset owner to continue to earn revenue without the need to develop a new asset from scratch by enabling an existing asset to continue generating beyond its expected typical lifespan. It also reduces outages by replacing old equipment with new, more efficient kit.

"Repowering represents a clear opportunity for owners to modernise their portfolios with the newest technology available, to better integrate the variable solar resource into the electricity grids for example, through the installation of the newest inverters compliant with the latest development in the national grid codes, to harness higher percentages of the solar energy and ultimately achieving a significant economic benefit," Simone Mandica, team lead at UK-based asset manager WiseEnergy says.

The life expectancy of an asset is an important factor in repowering, with improvements to modules extending their operational lifespan to between 30-35 years.

"From a financial perspective the possibility that the plant will be operational for [an] additional 30-35 years, instead of the remaining 15-20 years, will make the revamping investment more attractive, i.e. higher IRR and higher NPV," Mandica says.

Indeed, usually the only complication to extending the plant life is the lease agreement, if there is one in place, which provides a precise date for the decommissioning of the existing plant and therefore needs renegotiating. Based on Mandica's experience, in the PV market there has been a rise in interest in the fiscal and economic benefits of longer plant lifecycles, and in turn the negotiations for extending the lease have become increasingly common.

Other reasons for repowering include sites using obsolete equipment, for instance if a manufacturer no longer exists. While this doesn't make repowering necessary, a manufacturer being out of business means it takes a lot longer for faulty equipment to either be repaired or replaced due to there being limited availability, meaning the PV plant is shut down for a lot longer.

"It becomes a lot more attractive at that point for our clients to consider repowering options; changing out the old equipment for new equipment which is much more efficient," Natasha Kumar, managing director of BayWa r.e. Operation Services in the UK, says.

This also leads to better accessibility, with some new inverters for example having apps that give greater levels of understanding of how the inverters and the site is performing. This is compared to some older equipment, where you'd have to take much more of the site apart to do root cause analysis of any potential issues that are underlying, Kumar says.

Manufacturers going out of business is an issue run into by Enerparc. Inverter suppliers chosen for some of its projects are no longer in business so, in order to increase its stock, it changed out existing inverters before refurbishing, cleaning

and maintaining the legacy inverters and putting them back into its stock circulation, keeping the asset manager's technical availability high in the process.

Other benefits of repowering include being able to shrink the physical footprint while retaining the same capacity. Massimiliano Tarantino, head of wind and solar repowering and refurbishment at Enel Green Power, gives the example of an old wind farm with 30 wind turbines, each of them of 1MW rated capacity. By replacing legacy turbines with the latest technology available on the market today, an asset owner could maintain the same nameplate installed capacity using just five brand new turbines, all the while doubling power production in the process.

This is true of solar PV, too. PV modules are now hitting the market with outputs of 650Wp and greater, boasting at least three times as much power output as the corresponding technology of eight years ago. This means that less than a third of the area is now needed for the same nameplate capacity using these modules, which can free up space to build a new, potentially subsidy-free section of the plant.

This potential for expanding the capacity of a plant without expanding its footprint is becoming one of the key drivers in designing repowering strategies, according to Mandica, who adds that requests to assess constraints related to permitting or power export limitations, which could prevent the construction of a new section of the plant, are being made with increased frequency by owners.

New investment for an old project

On the surface, it seems like repowering should be a no brainer. Increased efficiencies and improved revenue are phrases any investor or asset owner loves to hear.

But while technology evolution is dramatically changing the renewable industry, Tarantino says the decision to repower an asset should instead be driven by the economic comparison between two possible options: maintenance coupled with lifetime extension and full repowering. These decisions are project specific and not directly driven by the latest available technology, but on the economic impact that such technology can have on a project's return.

Indeed, Kumar says it depends on how the site is performing, but the costs of repowering definitely play into the decision making due to there being more power density in some of the new modules.

"You've got more power in a smaller structure, and this ultimately increases capacity without having to increase the footprint. The modules are much more powerful and much more efficient, and that is much more appealing if you're looking at sites that have issues with some of the kit and the modules in particular."

This is true of some PV modules, but the solar market is also making a steady shift towards the production of large-format modules boasting higher rated power, while the production of smaller panels is decreasing correspondingly. That shift towards M10 (182mm) and M12 (210mm) size wafers, at the expense of M6 wafers (158.75mm) and smaller, is changing the shape of solar's manufacturing sector for good and, with it, repowering prospects too.

"This certainly represents a complication for the implementation of repowering plans involving the replacement of the old modules only. Indeed, the retrofit of modern larger panels on old plants poses a challenge in terms of their suitability for the existing infrastructure," Mandica says.

From a mechanical perspective, these modules are not compatible with the existing supporting structures produced for the old, smaller sized panels. Typically, old panels are 1m wide and 1.7m long, while modern panels exceeding 500Wp can be wider than 1.1m and longer than 2.2m, meaning the existing supporting structures will more often than not need a complete replacement, adding additional complexity and costs to repowering.

This then means that the older panels of smaller size and with a capacity no higher than 400 - 450Wp are often the best solution to avoid a complete rebuilding of the plants, Mandica says, which may not be economically feasible.

The financial element is an important driving force behind decisions to repower. Kumar explains that BayWa r.e.'s clients will only be looking to sign off on a repowering investment if the numbers stack up, "because it is a significant investment". The investment has already been made to build the asset, and the additional investment required for repowering might be one that hasn't been forecasted for and as such will require approval.

The Hill Farm PV site located in Bicester, Oxfordshire, UK, managed by WiseEnergy.

Recycling and reusing

Thought must also be given to what happens to the removed equipment when repowering. Typically, old panels will be recycled by companies providing waste management services. The panels will be delivered to a waste management facility, where they are disassembled to separate any recyclable component, for example the glass, the aluminium frame and the connection cables.

This is also true of inverters, although it is also common that spare components are taken from replaced inverters and then used on other compatible inverters. Mandica says the remarketing of old modules is an economic opportunity that brokers in the solar sector have started exploiting.

"Used panels even of nine or ten years of age, still operating at the expected level of efficiency and with no visual defects, have a market in the developing countries in the Middle East or in Africa."

The winds of change

Repowering of solar is very much still novel in many markets, but for wind it is road well-trodden. As such, repowering is not a journey that the solar PV market has to go on alone, with the wind market able to offer up some advice based on its own experience. Indeed, individual companies operating in both the solar and wind space may even have an advantage, being able to draw on the experiences of their own colleagues. This is certainly true of UK solar investor Bluefield Solar Income Fund. James Armstrong, managing partner of the fund's internal asset manager Bluefield Partners, describes the company's experience in repowering of wind outside of the UK as a "big differentiator for us", indicating that when solar repowering opportunities present themselves, Bluefield will be in a "very good place to do it".

The key piece of advice Vattenfall's acting head of development, onshore wind Sweden, Daniel Gustafsson, gives for the solar PV industry is: "It's primarily about building on existing relationships and trust that you have. It's about making sure that you nurture your local stakeholders."

For wind, it's very similar to developing a wind farm from scratch, with a need for a new permit, new land leases and new connections, although with repowering the long-term relationships with all the stakeholders have already been built up. "It's usually a smoother process when it comes to permitting," he says.

Enel's Tarantino suggests there are a number of lessons learned on repowering across the renewables sector that can be applied to the PV industry. Firstly, the decision should be taken on a case-by-case basis. Secondly, it is "always important" to compare between alternative investment scenarios, Tarantino, says, particularly between lifetime extension and repowering a PV plant. Lastly, the impact that repowering could have on power purchase agreements (PPA), shareholder's agreements and interconnection agreements shouldn't be underestimated. When it comes to offtake, repowering projects may have an impact on electricity price, on electricity generation volumes and on generation profile. Therefore, if the PPA provides for a renegotiation of the electricity price in case of changes in the generation volumes or profile, this has to be considered in the repowering business case. As such, an evaluation on whether it's worth amending the existing PPA, selling the extra electricity generation on a merchant basis or going for another PPA should be carried out.

"Additionally, as the PV industry matures and more components are decommissioned through repowering, industry leaders should prioritise circular solutions in managing their inventory," Tarantino says.

The UK playing catch-up

Understanding of why repowering is beneficial is not as common in the UK as other markets, according to Stefan Müller, COO of Enerparc. "You really have to take a lot of effort to explain to the asset manager of the investor in the UK why you're doing this, and then generally they don't want to touch it. They don't want to change a running system, even if they see a direct benefit of it," he says.

For Bluefield, repowering is something not yet on the cards, with its assets only being around 5-7 years old. As such, it's not a priority, although James Armstrong, managing partner of Bluefield Partners, said it is an "interesting idea" and something the team is looking at.

Indeed, repowering is more common in continental Europe, at least partly due to the assets being older, although other factors are also at play.

Müller explains that in Germany, while there is a secondary market, there aren't as many investments funds who cycle projects compared to the UK, where buying portfolios of assets and then reselling them is more common. In Germany the focus is on long term asset ownership, making repowering a more desirable undertaking. In addition, the banks in Germany have their technical auditors in house, making it easier to communicate.

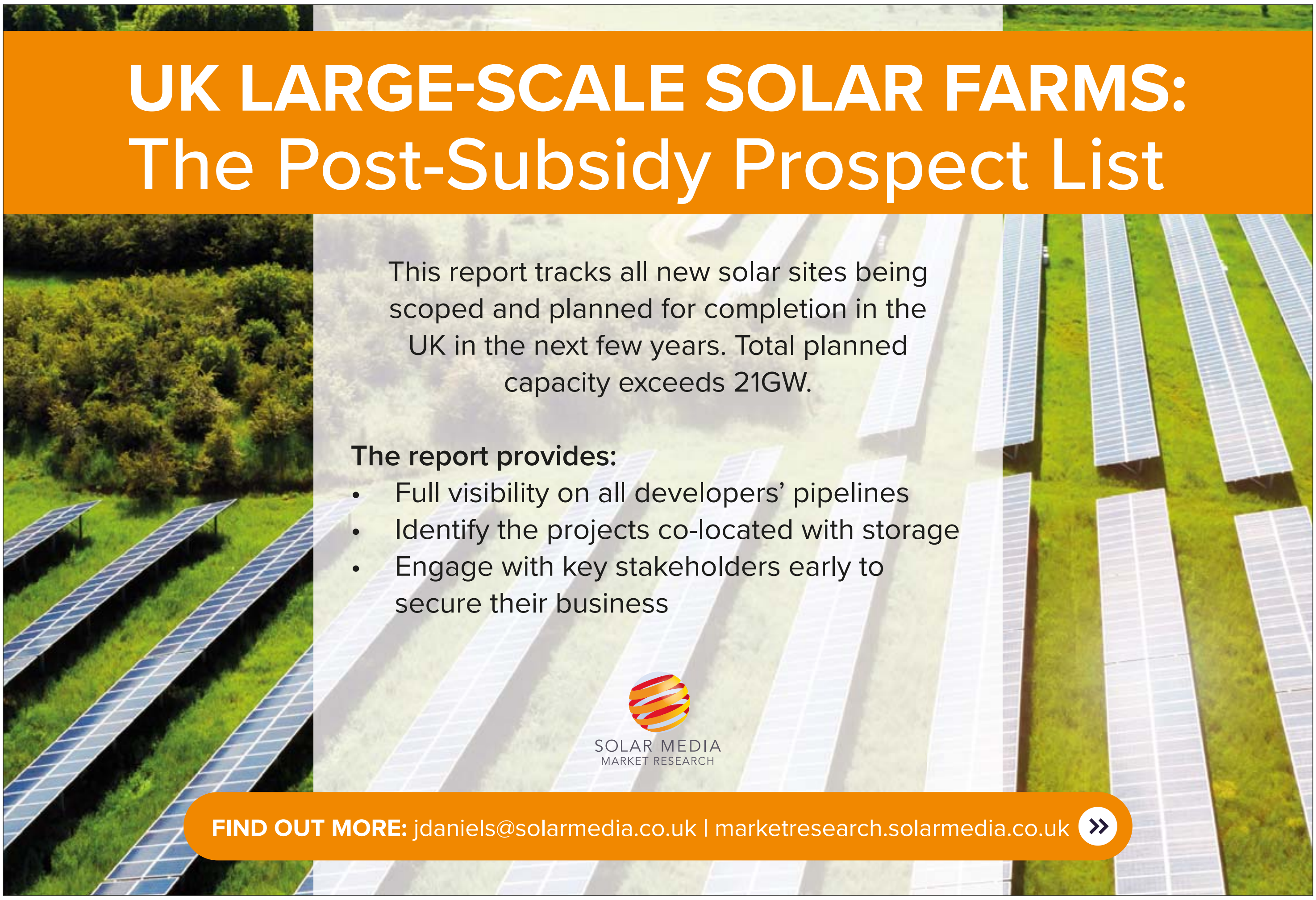
"In Germany, all of our projects are non-recourse financed, and the banks have their own technical understanding, and this makes things very easy," Müller says.

Mandica says Italy is also a particularly attractive market for repowering, due to the high feed-in tariff from which old plants benefit and the current relatively low cost of the PV equipment. In the last year and a half, WiseEnergy has advised its clients on the revamping of approximately 135MWp of plants and has directly managed the optimisation works on 40MWp. The investments it has recommended to its clients has achieved IRRs of over 11-12%, with this confirmed by its monitoring of performance.

However, repowering is also picking up pace in the UK. WiseEnergy has been working on the replacement of inverters for a portfolio of 10 plants totalling 67MWp. Repowering is being undertaken for this portfolio due to the rate of faults of the inverters having increased significantly in the last two years. Alongside this, repair of the inverters is "particularly problematic" as the manufacturer left the market a few years ago.

Indeed, while repowering in the UK is starting to kick off, Armstrong says a significant portion of PV in the country is under 10 years old, and as such would be expected to perform for the next 15-20 years without too much of a problem, meaning repowering is perhaps not on the cards for the vast majority of UK solar just yet.

Overall, it's clear that the decision to repower must be made on a case-by-case basis, with both benefits – better revenues, the potential to increase capacity and reduce reliance on outdated or obsolete equipment – and potential drawbacks, which are largely financial. It is a decision that shouldn't be taken lightly, however that's not to say it's not worth pursuing if both the technical and financial considerations stack up. While certainly not par for the course yet, the repowering being undertaken in markets such as Germany and Italy shows it is both possible and beneficial. And as assets continue to age, and modules and inverters continue to improve, making the prospect of repowering more attractive, the potential for repowering is likely to only grow. ■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Project briefing

The plant features ten floating islands that are tethered to the reservoir bed to prevent movement in strong winds.

Project name: Tengeh Floating Solar Farm
Location: Singapore
Capacity: 60MWp
Energisation date: July 2021

With an electricity mix currently dominated by fossil fuels and limited land availability for ground-mounted projects, Singapore is turning to floating PV (FPV) to increase its renewables capacity as it aims for 2GW of deployed solar by 2030.

The island city-state, which currently generates around 95% of electricity generation from natural gas, made significant progress earlier this year with the inauguration of its first utility-scale FPV plant.

Installed atop a reservoir and spanning 45 hectares, the 60MWp Tengeh Floating Solar Farm was built in less than a year despite COVID-19 challenges and is now able to power Singapore's five local water treatment plants while also contributing to the national electricity grid.

The project involved a collaboration between the country's national water agency PUB and local energy company Sembcorp Industries, as well as a host of contractors. When the plant was inaugurated in July, Sembcorp CEO Wong Kim Yin described it as "a crown jewel in our portfolio and a showcase for Singapore".

The success of the project has since led PUB to explore the development of two more utility-scale FPV plants as it aims to benefit from the dual-purpose of its reservoirs: clean energy generation to offset its energy consumption and storage of water to drink after treatment.

One of advantages of deploying floating solar systems on reservoirs is their higher efficiency compared to ground-mount projects, primarily due to the cooler reservoir environment, says Jen Tan, head of integrated solutions (Singapore and Southeast Asia) at Sembcorp Industries, adding that solar panels in open waters do not experience shading from nearby buildings, further enhancing their ability to maximise energy generation.

"In Singapore and other major cities in Southeast Asia, floating solar is one of the key sources of renewable energy production as it will help to overcome our physical land constraints," she says.

Innovative construction techniques

The Tengeh reservoir, located in the west of Singapore near the border with Malaysia, was initially used to host a 1MWp floating solar testbed that was deployed in 2016 to compare FPV solutions and study the economic and technological feasibility of deploying large-scale systems. Comprising ten types of floating structures and PV modules constructed by nine different companies, the testbed was managed by the Solar Energy Research Institute of Singapore (SERIS).

"At that time not much was known yet about the impacts and benefits of floating solar," Thomas Reindl, deputy CEO at SERIS, tells PV Tech Power. "Over the years we learned about the energy yield gains, challenges during operation, and PUB also evaluated whether there are any adverse environmental impacts."

The results from the site were favourable and showed that FPV systems performed 5 - 15% better than a typical rooftop solar PV system in Singapore, according to PUB, which then carried out environmental and engineering studies before deciding to proceed with the utility-scale installation.

PUB launched a request for proposals in 2019 to invite private sector companies to design, build and then own and operate the large-scale facility for 25 years, with Sembcorp Floating Solar Singapore awarded the contract in early 2020.

Jen Tan says one of the main challenges in developing the plant was ensuring that materials used will be durable for at least 25 years. "As FPV is relatively new, there was no 25-year case study available. Hence, the testbed that was already built by PUB in 2016 offered very important insights," she says. Based on studies from the test sites, Sembcorp had sufficient data that allowed it to select a system that is durable, environmentally sound and suitable for the local climate.

When construction began in August 2020, PUB and Sembcorp said each component of the system was designed and selected based on Singapore's climate in order to maximise energy generation, including the choice of double-glass modules to enhance durability in the wet and humid environment. The plant includes more than 122,000

Key facts

- Modules: more than 122,000, primarily Trina Solar's 210 Vertex dual-glass panels
- Site: 45 hectares
- Layout: ten floating 'islands'
- Construction time: 11 months

HOW CUSTOMISED INSTALL TECHNIQUES HELPED INSTALL SINGAPORE'S LARGEST FLOATING SOLAR PROJECT

Tengeh project timeline

- 2016: floating solar testbed launched at Tengeh Reservoir to study feasibility of deploying large-scale FVP systems on Singapore's reservoirs
- June 2019: PUB launches request for proposal, inviting companies to design, build and then own and operate the project for 25 years
- July 2019: DNV appointed technical advisor to provide tender support and proposal evaluation during the bidding phase
- February 2020: Sembcorp Solar Singapore appointed to construct the project
- May 2020: PUB and Sembcorp sign 25-year power purchase agreement
- August 2020: Construction work starts
- July 2021: Project completion

panels and primarily features Trina Solar's 210mm Vertex dual-glass modules, rated at 490Wp.

The scale of the installation required significant manpower for construction, which coincided with the country entering a circuit-breaker coronavirus restriction period. To comply with government measures, Sembcorp developed a playbook to keep workers safe, segregating the site into different zones to reduce intermingling.

Innovative ways of working were needed to mitigate the impact of the pandemic on manpower resources and supply chain constraints. Sembcorp implemented a new engineering technique to design a custom-built jig that ensured a standardised process to tighten the nuts and bolts during the mounting of solar panels onto its floats – a process that the company said increased the rate module assembly by up to 50%.

Despite the challenges, the project was completed in just under a year and was the result of a collaboration between several stakeholders – engineers, contractors and consultants – that Jen Tan says joined forces to "develop cutting-edge engineering and construction techniques". Quality assurance company DNV was originally contracted by PUB to be a technical advisor for the plant, while Sembcorp worked with partners such as Sungrow Power Supply and Shanxi Electric Power Engineering.

Additionally, a collaboration with Quantified Energy Labs, a technology spin-off from the National University of Singapore, saw advanced drone electroluminescence imaging technology deployed at the project. This technology captures X-ray-like signals emitted by modules to pinpoint potential module defects that could have been caused during the manufacturing or installation stages.

The project's performance and reliability are now backed by a digital monitoring platform that features safety cameras, video monitoring and alerts that help to track wind speed, solar irradiation and the ambient temperature. It also detects abnormalities that may indicate potential overheating and fire hazards.

"Some floating projects lack smart surveillance on the physical health of their FPV systems, so we built and implemented smart technologies to enhance active monitoring," says Jen Tan. GPS trackers also helped to remotely monitor and detect any misalignment in the positions of the array islands, which are tethered to the reservoir bed to prevent movement in strong winds and ensure worker safety during inspection.

Limiting environmental impacts

The main concern PUB initially had with deploying solar on reservoirs was the potential impact on surrounding environment, biodiversity and water quality, especially important given the Tengeh reservoir supplies drinking water.

> "We were mindful of the need to ensure minimal impact on water quality and the environment, especially during the construction phase"

The agency conducted environmental studies at Tengeh reservoir between 2015 and 2018, covering the potential impacts of the FPV system on wildlife, water quality and the microclimate. Results showed no observable change in the reservoir's water quality and no significant effect on the surrounding wildlife.

PUB worked with Sembcorp to put in place an Environmental Management and Mitigation Plan to minimise any impacts on the reservoir. That plan included the monitoring and management of biodiversity, water quality, sediment quality and noise pollution before, during and after construction of the project.

"As the water in the reservoir is used to store rainwater for subsequent treatment into drinking water, and reservoirs are usually populated with wildlife, we were mindful of the need to ensure minimal impact on water quality and the environment, especially during the construction phase," says Chong Mien Ling, director of policy & planning and chief sustainability officer at PUB.

Following consultations with nature groups, it was decided to avoid the south of the reservoir so as not to encroach on the nesting area of the grey-headed fish eagle, a near-threatened species, and leave two-thirds of the reservoir's surface untouched, allowing wildlife to continue to forage and hunt.

Another consideration was the design of the anchoring and mooring system for the solar PV arrays. "For a floating solar farm, unlike a land-based or rooftop PV farm, it was critical to design a stable and supportive floating PV array that could last for 25 years of operations," says Chong Mien Ling. Floats were selected that are made of high-density polyethylene (HDPE) – a certified food-grade material that is recyclable and UV-resistant to prevent degradation from the intense sunlight exposure.

Gaps between the panels, which are coated with anti-reflective materials to minimise glare, are also said to allow for sufficient sunlight and airflow to enter the waters, supporting the ecosystem beneath, while aerators have been installed to maintain oxygen levels in the reservoir.

A blueprint for Singapore's future?

The commencement of the Tengeh project's operations marks a significant step towards enduring energy sustainability in water treatment, making Singapore one of the few countries in the world to have a 100% green waterworks system, PUB and Sembcorp said when the plant was energised.

Electricity generated from the farm is sufficient to offset about 7% of PUB's annual energy needs. And valuable experience gained from the Tengeh plant can be expected to support the country as it bids to reach 1.5GWp of deployed solar by 2025.

Research from SERIS published last year revealed that Singapore has more than 4.5km2 of usable area for floating solar deployment, representing about 12% of the total area that was found usable for PV installs in the country, with the rooftop segment showing the strongest potential. The report found that only a fraction of the city-state's water bodies can be used for FVP due to restrictions such as environmental concerns as well as competing uses such as for recreational and military training purposes.

The 4.5km2 figure includes near-shore areas, which Reindl of SERIS says represent a great opportunity for floating PV in Singapore. "Near-shore areas are also suitable for multi-purpose uses of spaces, especially through the combination of floating solar with fish farming, desalination, or green hydrogen production," he says.

Adding to its existing fleet of rooftop solar projects at its facilities across Singapore, PUB announced in October that two FPV additional projects, each with a capacity of 1.5MWp and built above reservoirs, have started operations.

Chong Mien Ling says that in identifying suitable sites for future floating systems, PUB will take into consideration the reservoir surface area available, existing use (water and recreational activities) and potential environmental concerns. The agency is now exploring the development of two FPV plants on reservoirs that are expected to have capacities of 100MWp and 44MWp, with consultancy studies now underway.

"With solar energy being plentiful and future water demand expected to increase, we hope to harness more of this renewable resource to reduce PUB's carbon footprint, contributing significantly to our national climate change mitigation efforts," says Chong Mien Ling.

For Sembcorp, which announced plans earlier this year to increase its renewables capacity almost fourfold to 10GW by 2025, the company is now looking to develop more FPV projects across Southeast Asia, drawing on its experience from the Tengeh farm.

"The potential is there for the world to reach the terawatt peak range for FPV," says Jen Tan. "With the substantial amount of learning, the Sembcorp Tengeh Floating Solar Farm provides a blueprint for the design, construction, operations and maintenance of future large-scale floating solar PV systems."

Singapore accelerating solar deployment through whole-of-government effort

Having achieved its 2020 target of reaching 350MWp of installed solar, Singapore is aiming to make use of water bodies and rooftops to help reach a new ambition of having 1.5GW of PV deployed by 2025.

With high solar irradiance levels, Singapore's solar sector is expected to expand and see significant investment opportunities, according to consultancy Fitch Solutions, which said in research published earlier this year that land constraints result in limited scope for large-scale solar facilities, meaning any solar growth will be in the form of floating PV (FPV) or rooftop systems.

As the government pushes for increased renewables generation, Fitch said the country's Energy Market Authority lowered the fixed component of the license fee for generators ranging from 10MW to 400MW, reducing the cost of deploying solar, while application processes for solar installations were streamlined and simplified.

Solar is one of four 'switches' that Singapore is focusing on as it aims to change the way it produces and consumes energy. The other three are regional power grids, natural gas and low-carbon alternatives such as hydrogen.

"In the absence of other forms of renewables such as wind, hydro, or biomass, solar PV is the only viable renewable energy option in Singapore," says Thomas Reindl, deputy CEO at the Solar Energy Research Institute of Singapore, adding that there is a whole-of-government initiative to push for more PV deployment.

The country's Housing & Development Board launched the sixth tender under its SolarNova programme earlier this year to support the deployment of 70MWp of solar systems at apartment blocks and 57 government sites.

Another initiative from government agency JTC Corporation called SolarLand is focused on deploying PV systems on vacant plots of land. Energy company Shell signed an agreement earlier this year to explore the development of a solar project with a capacity of at least 72MWp at a landfill site as part of that programme.

Finally, national water agency PUB is supporting FPV deployment on the city-state's reservoirs. "Solar energy is the most viable form of renewable energy for Singapore," says Chong Mien Ling, director of policy & planning and chief sustainability officer at PUB. "Our reservoirs, with large water surfaces, have good potential to harness solar power in land-scarce Singapore."

Reindl says all three programmes are competitive (through public tenders) and "receive strong resonance in the market".

Credit: PUB

Singapore intends to reach 1.5GW of solar capacity by 2025.

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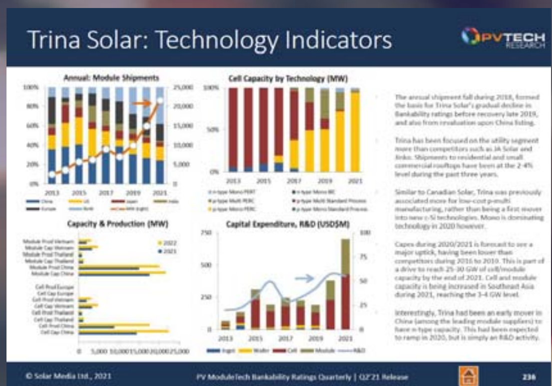

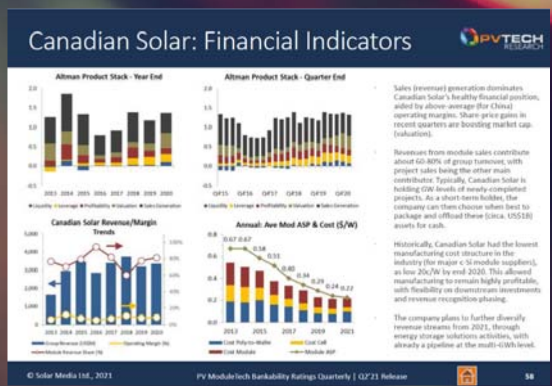

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The role of insurance and risk management in solar power project financing

Insurance | Prior to 2019, there was an ample number of insurers willing to provide renewable energy insurance, leading to plentiful, affordable cover being available for solar power project finance transactions. However, with increased claims and risks, price rises and lower availability of cover is impacting the sector. Duncan Gordon, head of Renewable Energy at specialist energy insurance brokerage and risk management firm Gallagher, provides an overview of how solar power project owners can navigate a challenging insurance market.

Project finance and loan agreements are necessary for the majority of renewable energy asset investments. Typically comprising on average a 30%/70% equity/debt split, lenders across a panel with a lead arranger will provide a credit facility which can be drawn down by the project owner, acting as borrower to the facility.

As part of the loan agreement, insurance requirements are outlined by the lender – specifying the type of insurance and level of cover the owner will need to arrange. Insurance policies are assigned to the lender via supporting notice of assignment documentation and the lender specified as a loss payee – a party who is authorised to accept money paid out under an insurance policy.

The typical types of insurance required to be taken out by the owner includes construction all-risk cover, which offers protection against loss or damage to the building works, construction plant, equipment and machinery. It also provides cover for third-party claims involving property damage or bodily injury arising in connection with a solar construction project.

Hail damage witnessed at a solar farm in Texas, US.

Delay in start-up (DSU) cover protects owners against financial consequences - such as loss of revenue or additional interest charges or refinancing fees - suffered following damage to the works that causes a delay in completion.

While marine cargo insurance provides cover against loss or damage to goods whilst being transported worldwide by road, rail, sea or air, marine DSU coverage offers protection against any consequential losses suffered when a project commencement is delayed as a result of goods being lost or damaged during the transit.

Once a solar power plant is up and running, operational all-risk insurance provides cover for physical damage or loss that affects the plant, while business interruption insurance helps to replace lost income if the project is unable to go ahead on a temporary basis due to the aforementioned physical damage or loss.

The changes seen in the insurance market in the last few years have highlighted the importance of owners working with an experienced insurance broker to ensure that cover is optimised, whilst also meeting lender insurance requirements.

Current market challenges

The renewable energy insurance market has undergone a significant adjustment over the course of the last two years. Whilst a common perception of insurers is that they always make profits from premiums, the reality over the last decade of underwriting solar (and more recently batteries) has seen most insurers repeatedly reporting annual losses.

The surge in volume of installed gigawatt-level capacity globally had seen steep growth in premiums received by the leading renewables insurers. However this premium growth was largely attributable to portfolios and projects or assets which had secured the market floor rating seen pre 2019. A few catalytic factors for change which coincided with the meteoric rise in installed megawatts was a broader range of claims, involving varying causes, territories, technologies and magnitudes. This affected annual loss ratios (the overall ratio of claims to premium earned) which saw substantially inflated underwriting losses.

Notable single asset natural catastrophe claims such as a US$80 million hail claim to a solar asset in Texas, wildfire claims across North America and windstorm events in Puerto Rico greatly impacted these consecutive year underwriting performances. The significant rise in volume of events caused a tipping point for the market which had already been challenged by the evolving attritional losses - which are more common, minor events resulting in damage, as opposed to major incidents such as natural catastrophes, for example - caused by human error in workmanship, mechanical and electrical breakdown failures and weather damage, which have accompanied the rapid rise in renewables. Relatively, these loss frequencies are low when compared to the volume of growth and installed megawatts but impactful when compared to the low premium rates which supported that crucial growth period.

This eventful period resulted in almost all renewable energy insurers changing their approach to underwriting. This market wide adjustment took place over an 18-month period, firstly in Europe followed by Asia and North America, reaching unanimity by January 2021. The common message being broadcast was that the shift in approach to underwriting was necessary for the insurers to be able to remain in business, and to support the continued growth of the industry.

This was also reinforced by a number of insurers closing down their renewable energy operations due to significant repeated annual loss. In some instances, premiums doubled.

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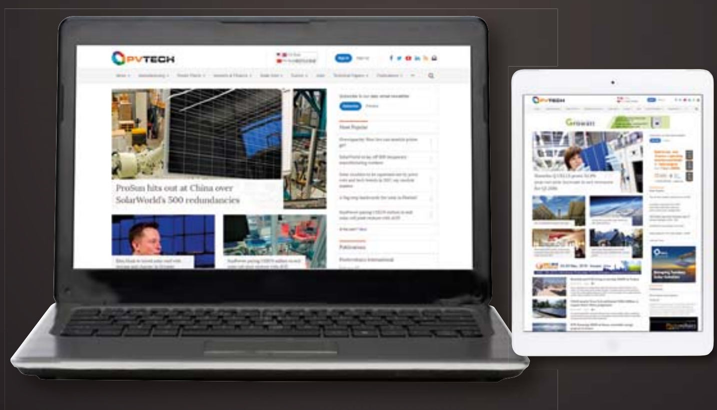

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This has been a period where tactful insurance broking has been crucial in order to minimise renewal premium increases for project owners – the strategy overall being to secure and offer pricing stability from the market to give greater insurance cost certainty for forecasts of capital expenditures (Capex) and operational expenses (Opex) financial models.

Lender insurance requirements

An important shift also took place regarding aspects of the insurance cover that insurers were now willing to give. Prior to 2019, the insurance annex of project finance agreements typically outlined requirements from lenders, which usually included broad coverage extensions and low deductibles - meaning the amount of money that a party is responsible for paying towards a loss before payment for a claim is made. Maximum permitted deductibles would typically fall in the range of €5,000 (US$5,600) to €25,000 (US$28,100) for property damage, with a timeframe of up to 21 days for any delay in start-up.

Almost in sequence, despite being a competitive marketplace, the impact of sustained losses had been so great that at renewal insurers started to increase deductible levels. The justification for this was the high frequency of attritional losses on solar and wind projects during construction and operations, with the resulting insurable damage events causing mounting insurable revenue losses. Without such change the adjustment in premium alone would not have been enough to enable the insurers to survive.

The growing involvement of lenders' insurance advisors (LIAs) in transactions – who conduct analysis of any project risk to make a full assessment of the hazards to which lenders are exposed– has exemplified that insurance is more than a mere checkbox for lenders. In recent years, there has been a greater impetus on the insurance broker to provide guidance to the LIA as to the extent of terms and conditions being offered by insurers, which then influences the insurance requirements stipulated by the lender within the project's finance loan agreement.

This dialogue between the owner's broker and LIAs has become more critical when renewing policies, with the challenge of securing the same historical low-level deductibles seen in historical finance agreements. Many lenders are now being asked to waive low deductible requirements embedded within their financing documents due to the lack of market availability, as many financing agreements were negotiated prior to the challenging market conditions being seen today.

For newer projects and finance agreements, the insurance broker engaging early with prospective lenders on behalf of the owner can ensure that a realistically achievable level of deductible is set as an insurance requirement.

Battery energy storage systems (BESS) risk mitigation

Following the market adjustment period, a key area of interest for insurers has been the hybridisation of solar and battery projects and many have set out clearer risk mitigation expectations since the start of 2021.

Due to historical BESS claims involving global fire losses which have occurred across multiple technology and system types, insurers now pay close attention to mitigation strategies for ceasing or limiting the effect of fire, should it arise either from external perils such as lightning or internal risks such as cell electrical failure. Insurers now require fire suppression and protection standards to be met in line with the National Fire Protection Association (NFPA) 855 Standard for the Installation of Stationary Energy Storage Systems, which focuses on separation between storage containers and the fire suppression system to prevent reigniting through thermal runaway [1].

> "While a common perception of insurers is that they always make profits from premiums, the reality... has seen most insurers repeatedly reporting annual losses."

Should sites be compact with little spacing between containers, such as a one metre distance, then this increases the risk of fire spreading from one unit to another, therefore boosting the chances of a more significant claim being incurred. Optimally, insurers are requesting a 2.5 metre distance between each unit and therefore this consideration should be looked at during development design, as site space can be restrictive.

Where fire suppression is concerned, there have been instances in the past where the inert gas systems within containers could not extinguish combustion, either as a result of oxygen being present due to inefficient seals or through thermal runaway and the temperature of cells continuing to increase without a cooling source such as water. If other measures of fire protection such as an on-site water supply and fire service in close proximity can be demonstrated, this can also be deemed favourable by insurers.

Though insurers are fairly open in regards to battery cell manufacturers, they have a more critical underwriting view towards contractors, checking that they have experience of complex installations such as step up transformers integration and solar production facilities in hybrid sites.

Solar technology risk management

From the perspective of major loss events and significant attritional loss events, the main insurer risks in solar are natural catastrophe perils and inverter failures. Insurers view those insureds more favourably in their risk management approach if there are positive aspects to consider, either in terms of risk mitigation or design features related to tracker design, notably to withstand high wind speeds; an inverter availability spares strategy, to mitigate revenue or business interruption-related loss through faster delivery to site and component replacement; and warranty tenures, given insurers scrutinise the varied provisions of warranty terms more closely now for assets over two years old.

In the case of warranties, there have been protracted issues which have arisen where technology providers - including panels, inverters, trackers and perhaps transformers manufacturers - are in financial difficulty. Insurers typically look to underwrite solely 'Tier 1' technology which implies financial stability. The solar boom in growth of the previous 10 years saw many manufacturers come and go but supply and demand has balanced for a more sustainable supplier space. Moreover, where credit risk is present to owners (and not insurance backed by a robust extended warranty product) they generally select only 'Tier 1' providers.

Based on historical trends, the standard period for typical inverter warranties has been seven or 10 years, which is optimal, and 10 to 25 years for panel warranties. Insurers can occasionally look to apply out of warranty deductibles for assets which have had a particularly lively claims history.

Construction phase risks

The build volume of solar has seen a wider pool of contractors stepping in to the sector with little experience of solar structures and technology, and drawing in additional unskilled manpower. In some cases, this has led to potential workmanship defects, with workers not being equipped with the appropriate skills, tools or training to complete the work competently.

Another common feature of most project builds are delays due to shipment scheduling, site works being delayed due to weather, supply and access. Therefore when a damage event occurs, it often causes an additional delay to a project already behind schedule. Since the market adjustment, extensions of construction policies are scrutinised more than ever by insurers who keenly look at the new timescale of delivery, testing and completion of the substation at the site to ensure it has an appropriate buffer for contingencies.

Other potential risks include transit losses, which can be common as a result of truck or container falls and damage suffered during shipment.

In Europe in particular, cable theft has become more common. Loss to cable equipment can easily incur a claim, wiping out in excess of an entire premium for a construction project. Flood damage can occur to sites during build phase in laydown when equipment is temporarily on the ground a few days and a flash flood occurs. There is also a risk of wind damage to trackers or their mounting structure if there has been an error in the build method or design methodology, which means they are incapable of withstanding high wind speeds in multi directional scenarios, as seen in undulating topographies.

Operational phase risks

It is fair to say that the rapid rise in solar capacity has seen risk exposure increase due to the varied technology providers of panels, inverters and transformers bringing up less robust track records, and many claims incidents of inverter failure in particular have occurred. These are often failures within a specific batch that have been destined to fail when installed by a contractor who has applied the same technique involving wiring, connection or software to a whole series.

Additionally, the vast volume of solar sites globally are located in natural catastrophe exposed areas, and insurers worry from a Probable Maximum Loss (PML) perspective - the value of the largest loss that could result from a natural disaster - if a substation is being exposed to wind storm or flood as this could incur a full 12 months of revenue lost, which business interruption insurance cover would indemnify.

> "The vast volume of solar sites globally are located in natural catastrophe exposed areas."

More common is wind and flood causing significant claims where the mounting structure has not been strong enough, especially now with trackers which can be more vulnerable to wind as a result of poor design, or panels which are not lifted high enough above ground level and are therefore susceptible to flood damage.

How to maximise value from the solar insurance market

More focus is being placed by insurers on risk management strategies when considering taking on a risk and there are a number of actions that owners can take to optimise risk-related procedures and controls, and maximise insurance outcomes.

Owners should be able to demonstrate that contractors working on the project have had prior experience of working on similar types of solar PV projects, especially those involving trackers, and in the same territory as the project is based, with an installed megawatts list – reducing the risk of installation and construction error.

Securing long term and robust warranties from well-known and reliable 'Tier 1' manufacturers can help to provide insurers with confidence about the performance of each of the components of the solar power system.

Insurers expect to see robust operations and maintenance (O&M) practices in place ensuring that plant infrastructure and equipment are well-maintained including regular vegetation management, removing any weeds growing around solar installations which can create shading, potentially reducing the functionality of the system; clearing snow and ice from panels to prevent any damage; and heat thermal monitoring to detect any risk of the system overheating.

A realistic project timeline should be made available to the insurers from the owner and their contractor pre-policy inception, so that the underwriting is accurate. This avoids insurers declaring a material change in risk if the substation is then set to arrive one to two months out from the commercial operation date (COD), which could have implications on cover. In reality, the substation is usually tested some one to three months prior to COD, so this should be factored into the project timeline upfront.

Prior to construction, any nuances on site – including those involving flood, wind and ground settlement risk – should be properly addressed with conditions reports and then design reports showing how those higher exposure aspects for the site have been fully mitigated by the pre planning of the owner and contractor and their design.

The value of a broker

Due to the fact that risks will vary from one solar power project to the next, there is no such thing as a one size fits all approach to insurance and risk management. To ensure the best possible outcome when securing insurance for project finance transactions and to meet lender requirements, engaging the support of a specialist insurance broker with technical awareness of common risk exposures in solar power projects and how these relate to policy wordings, is key. They will work with owners to identify project risks, advise what type of insurance cover is appropriate, and make sure that cover is tailored to project requirements. ■

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Duncan Gordon is head of Renewable Energy at specialist energy insurance brokerage and risk management firm Gallagher.

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73 **NEWS**
Leading news from the worldwide energy storage sector

75-76 **Stopping thermal runaway six minutes before it starts**
Steve Kennny from Honeywell Building Technologies highlights the importance of detecting off-gases

78-79 **Battery storage fire safety is everyone's business**
Paul Rogers from the Energy Safety Research Group talks to Andy Colthorpe about the pressing issues of fire safety

80-83 **Neighbourhood batteries in Australia**
By Australian National University's Battery Storage and Grid Integration Program

84-89 **How to design a BMS, the brain of a battery storage system**
Brill Power's Christoph Birkl, Damien Frost and Adrien Bizeray discuss the development of battery management systems

Energy Storage NEWS

Introduction

Welcome to the latest edition of 'Storage and Smart Power,' brought to you by Energy-Storage.news.

"Plus ça change, plus c'est la même chose"… "The more things change, the more they stay the same".

The phrase coined in 1849 by French writer Jean-Baptiste Alphonse Karr has aged well, because you can interpret it any way you like.

This time last year we were discussing the enormous progress made by the energy storage industry and how the accelerating rate of progress would be the energy storage story in the coming years, from innovation to deployment.

Yet, as with 2019, 2020's end came with a realisation that however strong the energy storage industry was becoming, the future of humanity and earth was still bleakly coloured with the overwhelming reality of climate crisis.

Since then, what's changed and what's stayed the same?

We've had the COP26 conference, at which some agreement was eventually considered better than no agreement. We've had energy crises in many parts of the world, some directly before COP26, which can't have helped. We've had fires, storms, floods and all the other stuff scientists warned us about. The temporary rise in air quality during the lockdowns wasn't deemed worth holding onto.

Yet we've also had another year of incredible progress in the energy storage industry. Almost every week a new regional market emerges, or a new set of opportunities in an existing market opens up. BloombergNEF analysts described the 2020s recently as an energy storage decade. It's hard to argue with that, based on what we're reporting through Energy-Storage.news every day.

This decade has to be the decade of energy storage. It must be. Many many gigawatts and many many more gigawatt-hours of energy storage are needed around the world.

In this edition of Storage and Smart Power, we take a deep dive into many of the factors influencing deployment.

Leading off with 'How to design a BMS', from a team at Brill Power, an Oxford University spinout which recently had its own proprietary BMS technology verified by DNV.

We hear about how the BMS acts as the brain of a battery storage system and all of the complex computations, calculations and control functions it needs.

This time last year a team from Energy Safety Response Group (ESRG), specialists in energy storage system fire safety wrote a piece for this journal on 'What the fire service wants you to know about your battery'. This time out, I spoke with ESRG founding principal Paul Rogers, a former firefighter with subject matter expertise in energy storage, about how the industry needs to approach non-industry partners like fire departments and local authorities.

On a related subject, in 'Stopping thermal runaway six minutes before it starts,' Steven Kenny, general manager for Advanced Fire Detection at Honeywell Building Technologies talks about the importance of being able to detect off-gases as an important line of fire safety defence in battery systems.

Finally, while it's easy to get excited about the bigger and bigger battery storage projects that are springing up around the world, distributed systems will have an exciting role to play to.

Experts at Australian National University offer an in-depth look at 'neighbourhood batteries' and how they can help ensure no one is left behind in the energy transition.

Well, another eventful year passes by. Thank you to all our supporters, sponsors, partners and of course, to you, our readers. Thank you to all of you working hard to make the future brighter.

Andy Colthorpe
Solar Media

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Fluence IPO raised company valuation to US$4.7 billion

Fluence's initial public offering (IPO) raised just under a billion dollars, with all available shares of the energy storage company's Class A common stock snapped up as they listed on the Nasdaq Global Select Market.

In total, proceeds of US$998,200,000 were generated. This is because although the 31 million shares sold to the public at US$28 each raised US$868 million, underwriters decided to immediately exercise their options to purchase an additional 4.65 million shares in full.

The IPO was only open from 28 October until 1 November. Pricing of the IPO raised the company's valuation to about US$4.7 billion.

Credit: Fluence.

Fluence's Gridstack BESS solution, part of the company's sixth generation of battery storage products.

LG Energy Solution lithium deal with 'sustainable supplier'

LG Energy Solution signed a six-year lithium concentrate off-take deal with supplier Sigma Lithium with commercial delivery to begin in 2022. Canada-headquartered Sigma has been producing battery-grade lithium concentrate at a demonstration plant in Brazil since 2018 and is focused on being able to provide large volumes of "green and sustainable" high purity lithium to the global market. It has claimed its production processes and use of hydroelectric power are among factors that will enable it to achieve net zero emissions status by 2024. LG Energy Solution will purchase an initial 60,000 tonnes from 2022 – 2023, with the amount increasing to 100,000 tonnes per year from 2024 to 2027.

Honeywell launches flow battery

US-headquartered multinational conglomerate Honeywell has developed a new flow battery, which it claimed is capable of storing and discharging electricity for durations up to 12 hours. The technology will be tested by major utility company Duke Energy in a 400kWh system configuration in 2022. After that, Honeywell wants to scale up to a 60MWh pilot project the following year.

Like other flow batteries, the technology offers the chance to store more energy simply by making the tanks that store liquid electrolyte larger. The battery does not degrade even with heavy use over time and is designed for a 20-year expected lifetime. The company has not revealed details of the battery chemistry yet.

Overheating incident at world's biggest BESS

An overheating incident was reported in September at the world's biggest battery energy storage system (BESS) project, Moss Landing Energy Storage Facility in California.

Some of the lithium-ion battery modules overheated on Saturday, 4 September, in the 300MW / 1,200MWh Phase I of the 400MW / 1,600MWh plant. Safety features kicked in, detecting that temperatures had exceeded operational standards in a limited number of modules. Targeted sprinkler systems aimed at those affected modules were triggered. Phase I was taken out of action immediately after the incident while Phase II, housed in a separate building, remained operational.

Project owner and operator Vistra Energy, battery rack supplier LG Energy Solution and energy storage technology provider Fluence and external experts immediately began investigations.

Australia introduces Five-Minute Settlement in National Electricity Market

New National Electricity Market (NEM) rules came into effect in October in Australia, with a boost in battery storage investment expected as a result.

The change primarily concerns the introduction of Five-Minute Settlement (5MS) of wholesale electricity market prices in the NEM, replacing the 30-minute wholesale electricity spot market settlement period rule which has been in place since 1998.

The Australian Energy Market Operator (AEMO) had determined in 2017 that the rule change was coming. It had been scheduled for introduction in mid-2020, but the COVID-19 pandemic caused AEMO to delay it until this October.

5MS is set to be "massive" for battery storage, Energy-Storage.news heard earlier this year in an interview with Lillian Patterson, policy and regulations expert at Australian national trade group, the Clean Energy Council.

ESS Inc becomes 'US' first publicly-traded long-duration energy storage company'

Shares and warrants of iron flow battery provider ESS Inc commenced trading on the New York Stock Exchange (NYSE).

Shareholders in special purpose acquisition company (SPAC) ACON S2 Acquisition Corp voted to approve a business combination with ESS Inc, which then went ahead and created the combined, NYSE-listed entity.

ESS Inc is the only global manufacturer of a flow battery technology based on iron and saltwater electrolytes, packaging them into energy storage systems for commercial and industrial (C&I) and utility-scale applications.

Along with Softbank's SB Energy, other investors in the manufacturer to date have included Bill Gates' Breakthrough Energy Ventures.

BloombergNEF predicts 'energy storage decade'

The 2020s are "the energy storage decade," and the world will surpass a terawatt-hour of installations by the time they are over, according to predictions made by analysts at BloombergNEF.

From 17GW / 34GWh online as of the end of 2020, there will be investment worth US$262 billion in making 345GW / 999GWh of new energy storage deployments, with cumulative installations reaching 358GW / 1,028GWh by 2030, the firm forecasts in the latest edition of its Global Energy Storage Outlook report.

Just over half of that new capacity will be built to provide energy shifting, storing surplus solar and wind generation for dispatch to the grid and to be used when it's most needed at a later time. This is already being seen in the growing popularity of renewable energy-plus-storage projects, particularly solar-plus-storage.

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Stopping thermal runaway six minutes before it starts

Fire safety | Crucial to clean power generation, battery energy storage systems need advanced fire protection. Steve Kenny, general manager for Advanced Fire Detection at Honeywell Building Technologies talks about why the detection of off-gases is an important line of defence.

Credit: Honeywell Building Technologies.

Smoke and off-gas detection monitoring sensors, mounted on top of lithium-ion battery racks.

Wind and solar farms, microgrids, data centres and telecom facilities have at least one thing in common: they rely on battery energy storage systems (BESSs) made of thousands of lithium-ion (Li-ion) cells. BESSs not only play a critical role in the transition to renewable energy and smarter power grids but also have become a key component of data centres and telecom hubs – both drivers of economic vitality worldwide.

The global market for utility-scale BESSs, valued at US$2.9 billion in 2020, is expected to grow at a CAGR of 32.8% from 2020 to 2025, reaching US$12.1 billion by 2025. If you factor in uninterruptible power supplies (UPS) for data and telecom centres, vehicle charging stations and all other energy storage applications, that number more than doubles. The total global energy storage market is projected to grow from US$7.8 billion in 2020 to US$26.8 billion in 2028.

Why have Li-ion cells become the enabling technology? They're affordable; they offer high energy density for their size and weight; they hold their charge longer; they're less prone to self-discharge than other battery types; and they require little maintenance and no periodic discharge.

Yet for all their advantages, Li-ion cells have vulnerabilities. For one, they require complex battery management systems (BMSs) to keep them operating within safe parameters of voltage, temperature and charge. If managed improperly or subjected to abuse, batteries can fail, resulting in off-gassing, excessive heat generation and if the electrolyte in the cells ignites, it can quickly escalate into a catastrophic, often explosive fire, that is extremely hard to extinguish (thermal runaway) that can spread to surrounding cells in an accelerating domino effect.

Three stages of battery failure

- Abuse factor: Electrical, thermal or mechanical abuse can potentially lead to thermal runaway. Electrical abuse occurs when the battery voltage limits are exceeded during charge or discharge. Because numerous cells charge or discharge simultaneously in a BESS, risk of individual cells sustaining electrical abuse increases. When operational temperature exceeds the batteries' heat specifications, it results in thermal abuse. Mechanical abuse refers to physical damage such as a crush, indentation or puncture.
- Initial cell venting (Off-gas): If the abuse factor continues, the battery liquid electrolyte will convert to gas, which will cause internal pressure build up inside the battery, exerting enough force to open a pressure relief vent or rupture the battery seals. This released gas is distinctly different than the release of gases at thermal runaway and often occurs several minutes prior to thermal runaway.
- Thermal runaway: With increasing internal battery temperature, the separator will melt down and rupture releasing smoke and igniting the electrolyte solvent. Gases emitted at this stage often include CO, CO2 and combustible gases. The resulting fire can produce temperatures exceeding 1,000ºC (1,832ºF) and spread to surrounding cells causing them to go into thermal runaway leading to a total system failure.

BESS fires are a global concern

Thermal runaway is not a hypothetical scenario. In the last five years, major BESS fires have made the news worldwide. Between August 2017 and April 2019, authorities in Korea investigated 23 BESS fires, prompting them to suspend operations at numerous facilities as well as commissioning of new BESSs. A 6MW BESS in Europe, still undergoing commissioning, was declared a total loss following a November 2017 fire.

In April 2019, four firefighters sustained serious injuries while battling a fire at a 2.16MW Li-ion BESS in Arizona. At the height of the blaze, crews measured dangerously high levels of hydrogen cyanide gas and carbon monoxide. Fire crews in the UK responded to a September 2020 fire at a 20MW grid-connected BESS, which took them nearly 12 hours to extinguish and blanketed surrounding neighbourhoods with toxic smoke.

BESS hazards challenge conventional technologies

A large-scale energy storage facility requires a battery management system (BMS) to monitor voltage, current and temperature and prevent abuse of the batteries, but relying on a BMS as the only layer of defence against thermal runaway is risky. For one, a BMS can't resolve single cell temperatures or voltages. Even with a temperature sensor on every cell, there can be hot spots that go undetected.

Conventional technologies such as smoke and fire detection, CO, CO2, lower explosive limit (LEL) monitoring often make up part of a comprehensive BESS safety solution. Smoke and fire don't typically develop until thermal runaway has already initiated, so these systems would not engage until it was too late to halt the chain reaction. CO, CO_2, LEL often don't occur in detectable concentrations until thermal runway.

In short, these technologies are reactive to thermal runaway rather than proactive in forestalling. Even if a single cell has reached the point of emitting smoke or fire, it may well be too late to stop the reaction from spreading to surrounding cells.

Fire suppression: too little, too late

Suppression is a BESS's last line of defence against fire when all preventive measures have failed. Yet, according to a recent study published in the Journal of the Electrochemical Society (JES), none of the primary suppression methods has been proven entirely effective in containing BESS fires.

Smothering technologies have little effect, as oxygen is often already present in battery components. Cooling systems that apply a continuous water mist to cool the battery are more effective but can cause short circuits, further propagating thermal runaway. Chemical suppression, including conventional fire extinguishers, can't arrest thermal runaway and can only suppress open flames outside the battery.

The JES study also found that, even after initial suppression, the exothermic chemical processes inside the cells often continue, creating a high risk of reignition. A 2019 DNV study that analysed different shipboard suppression systems to assess their effectiveness against BESS fires found there was no 'silver bullet' solution.

Initial venting (off-gas) detection gets out in front of thermal runaway

Detecting the early signs of failing Li-ion batteries is critical to enable operators and shutdown measures to respond proactively in time to prevent thermal runaway and catastrophic, often explosive fires.

Another study from DNV tested three technologies to assess their response times in detecting early signs of potential thermal runaway: off-gas sensors, cell voltage sensors and lower explosive limit sensors, which detect dangerous levels of combustible gas or solvent vapour. Of the three types, off-gas detectors displayed the highest sensitivity and accuracy. They averaged less than 10 seconds' response time after off-gassing started and 6 minutes 11 seconds before thermal runaway commenced. Neither the LEL nor voltage sensors activated until after thermal runaway had initiated.

Off-gas release	-381
Off-gas sensor	-371
Thermal runaway	0
Cell voltage	+7
LEL Sensor	+28

Source: DNV 2019 study, "Technical reference for Li-ion battery explosion risk and fire suppression".

The results also showed that shutdown measures combined with off-gas detection effectively prevented thermal runaway. Once off-gassing was detected, the battery system was electrically isolated, which prevented the cell temperature from increasing and thus stopped the propagation to adjacent cells.

Tailoring off-gas detection to BESS parameters

Detection of the initial venting (off-gassing) in a BESS, though, presents certain caveats. Such a system can't just be procured off the shelf because each BESS poses its own challenges, as noted in a 2020 UL study. The solution must be designed to a BESS's unique configuration – its geometry, volume, cell type, spatial layout and air-flow patterns. With these data in hand, designers can optimise the location and number of sensors to deliver the earliest detection using the least number of sensors.

Off-gas detection gives customers access to the first indication of failure and serves as a barrier to potential thermal runaway and catastrophic loss. By implementing this technology in renewable energy utilities, microgrids, data centres and telecom facilities, BESS owners can protect their people, assets and irrecoverable data – not to mention firefighters and other first responders. At the same time, they can avoid costly downtime, increase their resilience and help advance the transition to renewable energy.

Five ways to optimise off-gas/smoke detection in data centres

Fires pose a real threat to data centres, where they can spread quickly, putting employees at risk while destroying expensive hardware and irreplaceable data. With profitability, reputation and business continuity on the line, deploying an advanced, very-early-warning system that can detect the first sign of a potential battery failure is critical. Here are five design tips that can help protect people and mission-critical infrastructure while simplifying fire safety management.

- Assess the Risks: Start by focusing on three key areas to assess the factors contributing to fire risks: electrical systems, mechanical systems and administrative practices. Electrical systems can malfunction, overload or degrade over time. Mechanical system risks often stem from a malfunction in the HVAC system, generator or fuel lines. Administrative factors such as human error, poor housekeeping or inadequate storage protocols can also contribute to fire hazards.
- Know Your Environment: Understand the environmental challenges presented by data centres and telecom infrastructure to enable effective off-gas detection for Li-ion BESS areas and smoke detection. Cooling configurations, air flow characteristics, air temperatures and pressure differentials can vary dramatically from one area to another, and they all have a direct impact on the propagation of battery electrolyte vapours and smoke. In addition, data centres often house high security areas where access is limited, making installation and maintenance of off-gas and smoke detectors difficult. Other factors such as existing containment strategies, high air flow and complex ceiling configurations will determine the choice of off-gas and smoke detection technologies and location of the devices.
- Understand the Structural Challenges: Factor in ceiling height, concealed spaces, room geometry and equipment dimensions to understand how they'll affect air flow patterns, ventilation and, ultimately, the way off-gas or smoke can be detected. Certain areas may not be covered by fire safety standards or may require enhanced protection therefore a bespoke performance-based design (PBD) should be adopted.
- Keep It Accessible: Understand accessibility challenges when designing an off-gas or smoke detection system. System accessibility enables quick response to potential alerts as well as easy installation and maintenance. Awkward locations such as raised floors, ceiling voids or underground vaults can make system maintenance a tedious task that can lead to downtime or even security breaches in secure areas. Luckily, you can address this challenge early on by selecting control systems that can be mounted in easy-access areas, with the network of sensors or sampling network feeding information from hard-to-reach locations.
- Follow Regulations: Adapt to specific building regulations, if available, or follow an accepted Performance Based Design to deliver proactive early warning. Conducting an appropriate off-gas and/or smoke test during commissioning is a must, especially in critical infrastructure environments like data centres. Trusted manufacturers can advise on how to design a solution that checks all the boxes and goes beyond best practices to enhance safety.

Author

Steve Kenny is general manager of Advanced Fire Detection solutions for Honeywell. He has 27 years' experience in the thermal process and IoT industries. Steve is based in Rolle, Switzerland.

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Battery storage fire safety is everyone's business

Fire safety | With over 25 years' experience as a firefighter and now part of a group that specialises in battery storage safety, Paul Rogers at Energy Safety Response Group knows all about fire safety from both sides of the fence. He tells Andy Colthorpe about some of the pressing issues that need attention.

Lithium-ion battery storage has become a bankable, go-to technology for keeping power grids stable and for the integration of renewable energy. Yet, as deployments around the world grow, it's increasingly important to make sure everyone from policymakers to the general public can be confident that this relatively new technology is safe. Energy storage system fires are rare, but they can happen.

Local planning and permitting authorities and code officials are gatekeepers that could determine whether the world gets the energy storage it needs. Meanwhile it's firefighters that will be called upon, should anything go wrong. Relationships with these stakeholders matter.

In the US, Energy Safety Response Group (ESRG) was formed by a group of battery experts and experienced firefighters, offering fire safety services to everyone from energy storage manufacturers and project developers, to code officials and authorities having jurisdiction (AHJ), utilities, insurance companies and more.

ESRG's role in the industry includes educating firefighters on what to do in the event of a battery storage fire, but also, educating the industry on how to talk to firefighters, code officials and other stakeholders.

ESRG founding principal Paul Rogers was himself a Fire Department of New York (FDNY) Lieutenant for over 25 years. He led a project on energy storage systems (ESS) for the Bureau of Fire Prevention, becoming an ESS Subject Matter Expert (SME) in the process.

Preparing for all eventualities

Local plans examiners and code officials are beginning to understand that they need to look more in depth at fire safety for energy storage, he says, although new codes are very technical and tricky to understand.

On the other hand, the "vast, vast majority" of people supplying and deploying battery storage systems are behaving responsibly in trying to eliminate fire safety issues.

"They're building the systems so as to reduce the risk of these systems ever going on fire. We at ESRG look at it from what happens when it does go on fire."

Firefighters will always look at any new technology, especially energy tech, from that perspective, Rogers says. His team blend those two viewpoints: what to do in the event that a system does catch fire, versus how to operate a system so that it doesn't.

Energy storage industry professionals might also not think about what fire crews will need on the scene of an incident. As well as fires, explosions are a potential risk if gases are allowed to build up inside a system or enclosure. While deflagration vents or fencing can manage that risk, ESRG looks at the worst case scenario. What happens if the deflagration technology doesn't work, perhaps because fans aren't working or smoke release overwhelms the fan, in which case a lower explosive limit can result?

"We look at the impact. How is that impact going to affect the surrounding areas, and most importantly, the firefighters that are going to be up close and in front of these things?"

NYC's learning curve

When lithium-ion batteries were first coming into New York City, the fire service really did not know much about them, Rogers says.

"One of the first questions that we'd ask is, 'what happens when they go on fire?'"

The response given was: 'they don't go on fire'. But, as firefighters know, anything can potentially go on fire, "especially when there's energy stored inside of it," he says.

After extensive testing, Rogers and his then-colleagues at the FDNY realised energy storage fires are "low frequency, high risk events".

"The fire department won't be going to many of these things at all. But when they do, it's going to be very, very high risk. That's why these could be dangerous for the fire service".

A few years ago in New York, there had been many proposals to put lithium-ion battery systems into high rise buildings as replacement for lead acid batteries acting as uninterruptible power supply (UPS) units. This quickly became a concern for the fire department. Rogers identified that the explosion risk, even more than fire, was something totally new to have to deal with.

"As we started to know more and more about the lithium-ion batteries, with the idea of potential explosion hazards, the high heat release on the batteries themselves and the stranded energy after the fire has been dampened down, the reignition problems that they have, I went to the fire chief and said: 'I'm not concerned about these things being on fire, I'm concerned about after the fire, what do we do post-operations?'"

If the equipment is on fire, there are no gases accumulating. Then again, with fire comes high heat release inside a building, something that became a "major concern for the fire service".

As a compromise, installations of batteries were finally allowed, but only on rooftops. Going forwards, a new code has been proposed for New York City that will allow them back in, but only in limited quantities, if the City Council votes in favour. Even then, adaptation will be expensive.

ESRG also offers extensive testing services for battery cells and systems, including UL 9540A.

Credit: ESRG.

"It's going to be expensive to put in what the New York City Fire Department wants them to put in, in order to handle explosion controls and water delivery and other things — that will make it very difficult for the return on investment," Rogers says, although for new buildings, it may be much easier to incorporate those features into the design.

New York City is also considering introducing a Certificate of Fitness, "kind of like a driver's license," Rogers says, so that someone with requisite knowledge is available to liaise with an incident commander within two hours of being contacted.

This is also important, because the fire service needs to know when it's safe to call a situation as fully dealt with.

"Just recently out in Long Island, they had an incident where it was solar hooked into an energy storage system. They sat on it for four days! We see many examples of this around the country, where the fire service is sitting on it, wondering 'when can we leave?'"

Fighting fires, fighting misinformation

Of course it's not only firefighters that need to be comfortable with the safety aspects. ESRG is working in numerous regional energy storage markets around the US, including Massachusetts, California, Arizona and Texas.

Often, code officials are getting access to very shallow, or even plain wrong, information. Rogers said he was teaching a class where it became clear some of the students, including code officials, had been getting information from browsing the internet. Some had read that in the event of an ESS fire, people would need to be evacuated to at least a mile away. Simply not true.

"That becomes a major challenge in itself as the education is not there for people that are reviewing it, and don't feel comfortable allowing these things in. They don't have the information, as they're looking to install these things inside their jurisdiction."

Rogers refers to a recent academic paper comparing the explosion risk of battery storage to weapons of mass destruction. Its authors didn't understand how an energy storage system can fail and what happens when one does.

"They were trying to put everything together as if all of this system would blow up simultaneously, and that's not true at all. It is not how energy storage systems fail. There's cascading failures, it doesn't fail all at once. And if it goes on fire, the fire is consuming any gases that may be liberated as a result of the heat itself."

Know your audience

The industry needs to be proactively communicating directly with stakeholders, in language that can be plainly understood. Rogers said many already understand this need to communicate and that "word is getting out there that you probably need to start to speak to the fire service sooner rather than later".

Not doing so can have disappointing consequences. Rogers cites a recent example where ESRG was brought in at a relatively late stage of discussions. The company in question had reached out to the fire service for meetings.

"Unfortunately, the company know what they're talking about with their system, but they weren't able to articulate it and make that connection with the fire service. The meeting was ended abruptly as a result of them not being able to get their point across. That became a major challenge."

Successfully talking to the fire service means explaining exactly what the potential risks are. Then making them aware of the different layers of safety features and procedures that would need to be compromised for those worst-case scenario events to happen. Using the language, or jargon, that the fire department can understand is really important too, Rogers adds.

'Everyone needs to stick together'

The energy storage industry is getting better and better at putting in layers of protection to prevent explosion, which could include new technologies like the IntelliVent deflagration vent developed for low-cost licensing by Pacific Northwest National Lab or the off-gas detection systems discussed in Steven Kenny from Honeywell Building Solutions' article in this edition of PV Tech Power.

Then there's the battery management system (BMS), which Rogers says can play a vital role in safety, offering real-time insight into the ESS. More standardisation on the BMS and the implementation of what's known as a high Safety Integrity Level (SIL) would help the industry.

A quick final anecdote about stakeholder engagement illustrates two of Rogers' points in one:

Representatives of an energy storage installer attended a meeting at his FDNY headquarters in Brooklyn a while ago, when one of the visitor's phones lit up. She said there was a problem with one of her company's battery projects.

Rogers asked how she knew that. The answer was that the BMS found the issue and sent an immediate notification. The then-FDNY official asked why the fire service couldn't also get that data.

"She said we didn't need that data — didn't understand why we would. I don't need all the data, I need one point: if there's a rise in temperature, the fire service should know about that."

If a battery cell fails, but no propagation results and the system continues to run, it would be useful for the fire service to be able to determine that.

"When you have ninety to a hundred systems in one container, in one rack, in one module, and it's one cell [that has a problem], the fire service is conditioned to shut down everything. That's how we handle electrical emergencies. Shutting down everything. Can you imagine shutting down a hundred battery containers feeding the grid? This is why that education needs to get out there." ■

Neighbourhood batteries in Australia

Australia | Sometimes called 'community batteries,' energy storage systems are being installed at neighbourhood level in Australia. Experts from the Australian National University explain how this type of battery storage can benefit a very wide range of stakeholders.

Credit: Western Power

As Australia transitions its electricity supply away from fossil fuel-powered generators to renewable sources of energy, neighbourhood batteries are becoming an increasingly popular form of storage. There are more than one dozen neighbourhood battery projects currently underway across Australia, with a range of ownership and operation models.

It is now, in the early days of neighbourhood battery research development, design and demonstration that we can evaluate the various models and trade-offs inherent in these models. Technology can end up not meeting user needs, or result in negative unintended consequences if we don't step back to understand their impacts early on.

In the Battery Storage and Grid Integration Program at the Australian National University we have been conducting numerous studies that delve into the socio-techno-economic aspects of neighbourhood batteries. Our research has revealed that this type of battery can provide a range of benefits for all energy stakeholders, be they energy network operators, energy retailers, market operators, customers, governments, or local councils.

What these batteries have in common is that they are all located close to customers, connected to the distribution network, and can provide stored energy for up to hundreds of homes. They range in size from a wardrobe to a shipping container, have power capacities of about 0.1 - 5MW and complement household and utility-scale batteries.

Reversing a trend of 'haves and have-nots'

What makes neighbourhood batteries a particularly interesting form of energy storage is that they have the potential to address energy equity and provide benefits to all energy users. Some groups of people, particularly renters and those who do not have solar panels on their rooftops, but also people who might be socially and digitally isolated could all benefit from neighbourhood batteries.

These benefits could be economical, or an increased sense of autonomy and control over their local energy management. This contrasts with how rooftop solar has played out in the Australian context.

An example of a neighbourhood battery system in West Australia, installed in a trial by Western Power.

Historically residential solar has been a tale of the 'haves' and the 'have-nots'. Those who can afford to put solar panels on their roof and those who cannot.

Household solar uptake has not happened alongside a broader conversation about what kind of energy system we want. Neighbourhood batteries can hopefully spark those conversations. Our research tells us that people really want to be a part of these conversations and have long felt disconnected from energy decisions that affect them.

Neighbourhood batteries are sometimes referred to as 'community batteries' or 'community energy storage'. We elect not to use these terms because the word 'community' implies a degree of community involvement.

Some neighbourhood battery projects absolutely do have this element and we suggest community involvement is required as a principle. It is also the case that other models are allowed in Australia's current regulatory system that requires little or no involvement from the community. To encompass all models, we use the term *neighbourhood batteries.*

Australia, the distributed energy resources superstar

Australia leads the world in the uptake of rooftop solar, per capita, with one in four homes with residential PV[1]. Three million solar systems have been installed nationwide[2], that's nearly 1kW of panels per person. It is the enthusiastic adoption of rooftop solar by people that has made the country a distributed energy resources superstar.

Beginning a decade ago, the high uptake of solar PV amongst Australian householders was in response to feed-in tariffs and government rebates. It simply made good financial sense to install solar panels on your roof. A second reason is environmental in nature. Customers have been installing PV in recognition of the important role that more renewable generation will play in addressing the existential crisis that is climate change. A third reason is that Australians are seeking greater energy independence from a system that has made them feel disenfranchised.

Our work has revealed that many people feel a motivation that energy decision makers are overlooking. They feel the energy transition is not happening fast enough and in the way they would like it to. Buying solar is a way to show their defiance and send a signal to those in power that they are not happy with the way the energy transition is unfolding. For these householders, the financial benefits are just a bonus.

Integrating this vast amount of solar generation is a major challenge for network operators and there are several ways Australia is tackling this problem from smart software solutions, utility-scale storage, pumped storage and various demand response and other market mechanisms.

In Australia, also notably in the US states of California and Texas and many parts of Europe, grid operators are resorting to solar curtailment when there is not enough transmission capacity to cope with the generation of renewable energy. The infamous 'duck curve' graph indicates the discrepancy between peak electricity demand versus peak solar energy production. Neighbourhood batteries have a role to play in capturing the excess energy generation and storing it until it is needed. But this is just one of the benefits of this type of battery.

Defining and assessing the benefits

The ability to provide benefits to many stakeholders is one of the key reasons why we felt it was important to comprehensively investigate the opportunities for neighbourhood batteries. There are four key elements that describe a range of possible battery models[3].

It is important to remember that benefits have different definitions. The energy sector is used to thinking about benefits in terms of return on investment. But other stakeholders might be more concerned about decarbonisation, or whether the battery can make the community more resilient or even whether the battery could spark a conversation about collective opportunities for demand response.

With this in mind, the elements that will likely affect how the benefits are defined and accessed include:

» Battery ownership – who will own the battery, and what regulatory considerations might arise due to ownership? Crucially, how might battery ownership influence the prioritisation of benefits to different stakeholders?
» Stakeholder participation – who is a stakeholder in the battery's operation, and what is their legal and operational relationship with the battery? How do stakeholders benefit from their participation, and what technology is necessary to enable the battery operation?
» Network tariffs – what network tariffs are applied to energy flows into and out of the neighbourhood battery, and how do network tariffs unlock or impact the benefits that can be delivered to stakeholders?
» Services delivered – what market services, such as energy arbitrage and frequency support, can neighbourhood batteries deliver? What non-market services, such as network support (demand response, voltage regulation), do neighbourhood batteries deliver? How can services be value stacked to maximise the battery's utilisation and cost-effectiveness? Or maybe, due to community discussion, the most 'optimal' outcome may actually be an optimisation they can understand, meaning, perhaps not all value streams will be accessed.

> "The energy sector is used to thinking about benefits in terms of return on investment. But other stakeholders might be more concerned about...whether the battery can make the community more resilient."

By undertaking a socio-techno-economic analysis of various permutations of these four key considerations, we have been able to assess how different neighbourhood batteries create value for energy users, distribution networks, electricity retailers and the broader electricity system.

Our work has so far revealed that neighbourhood batteries can deliver five essential benefits. They can:

1. Improve the fairness of the energy system
2. Build trust in the energy system by sharing value transparently
3. Increase the hosting capacity of the network
4. Bolster local resilience, including socially, economically, and electrically
5. Be cost effective by delivering services to many stakeholders.

We note that more benefits may become clear as we roll out this technology at scale.

Value-sensitive design

As part of our social research[4] we conducted interviews and forums with industry stakeholders and members of the public. A general theme borne out of much of our research is that trust in the electricity sector is low. This finding alone should stimulate some reflection from key actors in the sector about how we could make the energy system more transparent and include people in key decisions.

People's interest in technology is usually multi-dimensional and reflects their experiences and needs. Usually affordability is only one element – for example, our participants were highly concerned about battery life-cycle, promoting local energy use, reducing carbon emissions, questions of fairness and how this technology would support the broader energy transition to renewables.

After we conducted our social research, we then considered different battery optimisation designs that reflected these different values.

The ***carbon-savings algorithm***, for example, operates the battery to minimise the carbon emissions of the neighbourhood's energy generation mix. A consistent theme among householders was the value of batteries in enabling more renewables and the decarbonisation of the electricity system. This algorithm might be chosen, for example, by a city community who choose to pay a little more for their energy in order to prioritise local decarbonisation.

For the ***self-sufficiency algorithm***, the battery operates to maximise the energy independence of the community, by storing locally produced solar energy. Algorithm design here was influenced by the community's enthusiasm for the idea

Credit: Horizon Power

582kW / 583kWh battery storage system in the remote town of Marble Bar deployed this year by state government-owned electricity supplier Horizon Power.

of local generation and local use of solar resources located in their own neighbourhoods. This algorithm might be chosen, for example, by a community from a coastal region of Australia which is at risk of isolation from the main grid because of bushfire or other natural disasters.

The ***timer algorithm*** instructs the battery to follow a simple fixed daily schedule. Although not the financially optimal choice, we tested this algorithm in response to concerns that were voiced to us about the 'gaming' of the energy market by incumbents. This algorithm is easy for non-experts to understand and makes it easy to monitor the distribution of benefits. Stakeholders often expressed a desire for transparency and explainability, and a desire for autonomy and control over their energy choices.

In practice, battery algorithms can be designed to optimise for more than a single objective for example, financial costs and decarbonisation values. However, we demonstrate that multiple values cannot always simply be 'value stacked' in an algorithm, rather, some values are inescapably in tension with one another, and trade-offs are required.

These trade-offs will be inherently political (influenced by different values), particularly because the values being traded off may be based on unrelated metrics (for example, dollars versus algorithm explainability) and some are not naturally quantifiable. For example, it is easy to design an algorithm to maximise revenue for a battery owner but challenging to consider how to design an algorithm that maximises energy users' autonomy and control. As we conclude in our paper[4], this will inevitably bias the design of algorithms towards the easily quantifiable.

The bias and explainability of neighbourhood battery algorithms

Research on the inherent biases of algorithms has grown substantially over the past decade, yet these are relatively new issues to energy researchers like us. Our work highlights that it will be essential to consider how these issues are explicitly encoded into the millions of devices that will underpin our future electricity grid. How can we do this in practice? In our paper, '*Applying responsible algorithm design to neighbourhood-scale batteries in Australia*'[4], we discuss the need for digital energy technologies to be developed through an 'algorithmic accountability in action' approach that aligns the behaviour of these technologies with public values.

Through our research we have demonstrated that battery control algorithms can be optimised to meet diverse needs however algorithms may also perpetuate bias and generate unfair outcomes. We raised three systemic concerns that we believe had been previously overlooked.

The first is the potential bias of algorithms to lead us towards easily quantified metrics, for example profits, costs, and voltage management. Our second concern relates to explainability. Even when algorithms provide simplified explanation, such as arbitrage to 'buy low and sell high', we saw that these methods can be applied to vastly different outcomes of battery profit, communal bill reductions or carbon emissions reductions.

A consequence of this opacity is that while financial approaches may claim to produce public benefit through improved market efficiencies and lower market prices, these claims may, in practice be 'gamed'. Even with regulatory controls and oversight, our research reveals it may anyway face backlash from the public in contexts where trust is low. Indeed, it is possible that the non-'optimal' timer algorithms may meet public needs because they relieve concerns about complexity and a lack of transparency.

This brings us to the third systemic concern around implications for community control. There is an important paradox here. Namely, the reliance on algorithms could both serve to reveal and open up the 'black box' of decision-making in energy systems through using methods to engage stakeholders in dialogue about values and trade-offs for the battery optimisation (enabled by the fact that some values are quantifiable).

At the same time, the complexity of optimisation algorithms and the likelihood in the Australian context for these to be developed by the private sector, without consideration of the public's views and values could further exclude stakeholders from understanding and participating in the energy system. Likewise, there remain important questions about the use of any behind-the-meter load data used in battery optimisation, in terms of data ownership and use(s).

Our findings emphasise the need to take a holistic view of the values and assumptions embodied in algorithms that will affect perceptions of the benefits and risks of storage technologies for individual users as well as other actors in the energy system. We believe this requires truly interdisciplinary work, as 'good modelling cannot be done by modellers alone. It is a social activity'6.

For new energy technologies, there are numerous methods for exploring potential effects of technologies, but it is key for these to be explored within specific cultural contexts. The need to anticipate and reflect public concerns in battery optimisation design is likely to be especially acute in privatised energy systems where key incumbents must prioritise shareholder values, over overarching public benefits or concerns.

The economics of neighbourhood batteries

The issue of network tariff reform has historically been a contentious one in Australia, in the context of high uptake of household solar. We have studied the operation of neighbourhood batteries under a range of local network tariff models, using current Australian electricity prices and current network prices as a reference.

Artist's impression of a neighbourhood battery system on a street in Melbourne, Victoria.

Credit: Pixii.

Our modelling shows that neighbourhood batteries would only be financially feasible if the local network tariff was discounted. This is due to the tariff applying to both the charging and discharging of the battery, meaning the system is double-charged.

Previous proposals to address this issue have generally either applied a discount to network tariffs for local energy flows or created a secondary energy market for peer-to-peer transactions. The former is expected to result in a zero-sum wealth transfer between networks and customers, and the latter has faced implementation and regulatory complexities.

Our modelling[5], however, demonstrates that a discounted local use of system (LUOS) network tariff could be introduced without the expected zero-sum wealth transfer, if a neighbourhood battery is included in the local system. This is due to the increased number of transactions on the network as the battery charges and discharges, such that the network receives the same revenue even though the network tariff is discounted. Network charges incurred by the neighbourhood battery owner can be offset by the revenue earnt from energy arbitrage. In this way, all stakeholders (network, customers, battery owner) can be financially better off compared to a system with no neighbourhood battery and the normal network tariff.

The clear recommendation from our analysis is that the price of LUOS needs to be less than half of conventional distribution network tariffs, allowing for mutually beneficial economic outcomes for all stakeholders.

The Neighbourhood Battery Initiative (NBI)

In 2021, the Victorian Government of Australia funded the Neighbourhood Battery Initiative (NBI) with the goal of demonstrating how this technology can support the energy transition.

In partnership with the NBI, the Battery Storage and Grid Integration Program is developing a framework that evaluates the social, technical and economic impacts of neighbourhood batteries, as well as developing a set of Neighbourhood Battery Guidelines.

These guidelines will focus on community engagement, partnerships and contractual arrangements, customer participation and technical specifications to deliver the full suite of battery services. Along with guidance for working with networks to identify locations where neighbourhood batteries could provide network support.

One of the projects funded by the NBI is Melbourne's first inner-suburban neighbourhood battery project; the Melbourne 'solar sponge' initiative. This multi-partnered project includes the not-for-profit organisation Yarra Energy Foundation, electricity network Citipower, City of Yarra local council and the ANU Battery Storage and Grid Integration Program.

The Yarra Energy Foundation is consulting extensively with the local community, holding numerous information and Q&A sessions, organising meetings, drop-in sessions and public consultation sessions in an effort to learn how the community wants to embrace batteries and energy storage solutions.

Neighbourhood batteries are providing an opportunity to shift to cheap, net-zero local energy. As the early trials into this technology begin, we need to ensure that we are focused on the best outcomes for energy users and the environment. Together, researchers like us can work with decision makers, communities, network operators, retailers and other stakeholders to ensure that we do not bake in technology designs that exclude and create community backlash, but instead reconnect people to the energy transition that they want. ■

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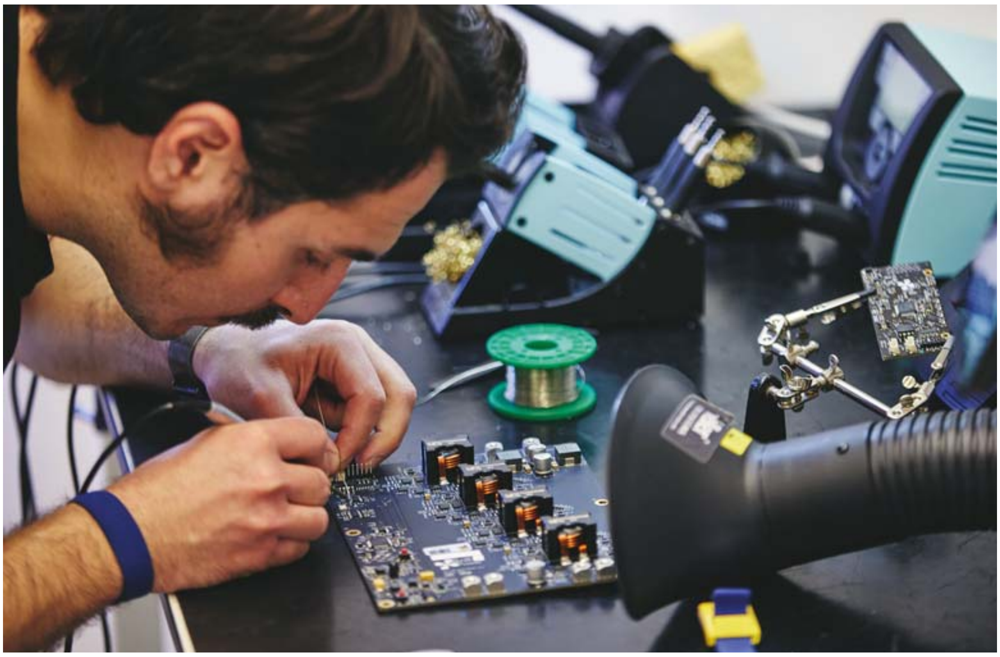
How to design a BMS, the brain of a battery storage system

Battery management | Battery energy storage systems are placed in increasingly demanding market conditions, providing a wide range of applications. Christoph Birkl, Damien Frost and Adrien Bizeray of Brill Power discuss how to build a battery management system (BMS) that ensures long lifetimes, versatility and availability.



Credit: Brill Power

BMS hardware in development.

Every modern battery needs a battery management system (BMS), which is a combination of electronics and software, and acts as the brain of the battery. This article focuses on BMS technology for stationary energy storage systems. The most basic functionalities of the BMS are to make sure that battery cells remain balanced and safe, and important information, such as available energy, is passed on to the user or connected systems.

Balancing is needed because battery systems are made up of hundreds, sometimes thousands of individual cells, which all have slightly different capacities and resistances. These differences increase over time as the cells degrade at different rates. If the cells are not balanced at least occasionally, their voltages will soon drift apart to an extent that the battery capacity becomes unusable.

Safety is ensured by keeping the cells within safe operating limits of voltage, current and temperature, which is particularly important for lithium-ion batteries. If cells get over-charged, charged at very low temperatures, or exposed to excessive currents or temperatures, they could develop faults that may lead to fires or explosions.

Information such as available energy and power cannot be directly measured, which means the BMS must compute it based on measurements of voltage, current and temperature. These computations are called state estimation and the results are passed on to higher-level systems, including user interfaces.

Before we look at BMS design considerations in more detail, it is worth describing the different types of BMS and industry requirements that inform design choices. The balancing approach is typically used to classify BMS types, although other design aspects play important roles, such as different approaches to state estimation and information flows.

Basic Pack Construction

Cells, or electrochemical cells, like lithium-ion cells are the smallest unit of energy storage within a pack. They come in various physical sizes which directly relate to their capacity. The minimum voltage of a Lithium-ion cell can be as low as 2.5V (for LFP cells) and the maximum voltage can be as high as 4.3V for NMC chemistries.

Cells are connected in parallel to increase the maximum current that can be drawn from the pack. A group of parallel connected cells are called a super cell. In general, the cells within a super cell will self-balance and there is no need to manage them further. Exceptions can include novel chemistries like lithium sulfur and chemistries with flat state of charge versus voltage curves operated in extreme C-rate conditions like lithium iron phosphate.

Super cells are connected in series to form a string. A battery pack usually consists of a single string. Connecting super cells in series increases the voltage of the pack, which is necessary in high power applications to prevent otherwise extremely high operating currents.

When adding cells to a battery pack configuration, the energy capacity increases. Therefore, adding parallel cells to a super cell increases the pack's energy capacity, as does connecting an additional super cell in series.

BMS types

Balancing approach

Passive balancing synchronises cell voltages at the end of the charge process by dissipating energy, which would have gone into fully charged cells, as heat via resistors. The advantage of this approach is the low component cost of the electronics. Disadvantages include that all cells are exposed to the same current, which means that the weakest series-connected cells limit the energy, power, lifetime and safety of the whole battery. Cell degradation is accelerated since the current on weaker cells is higher relative to their capacity, which can also cause localised hot spots that may

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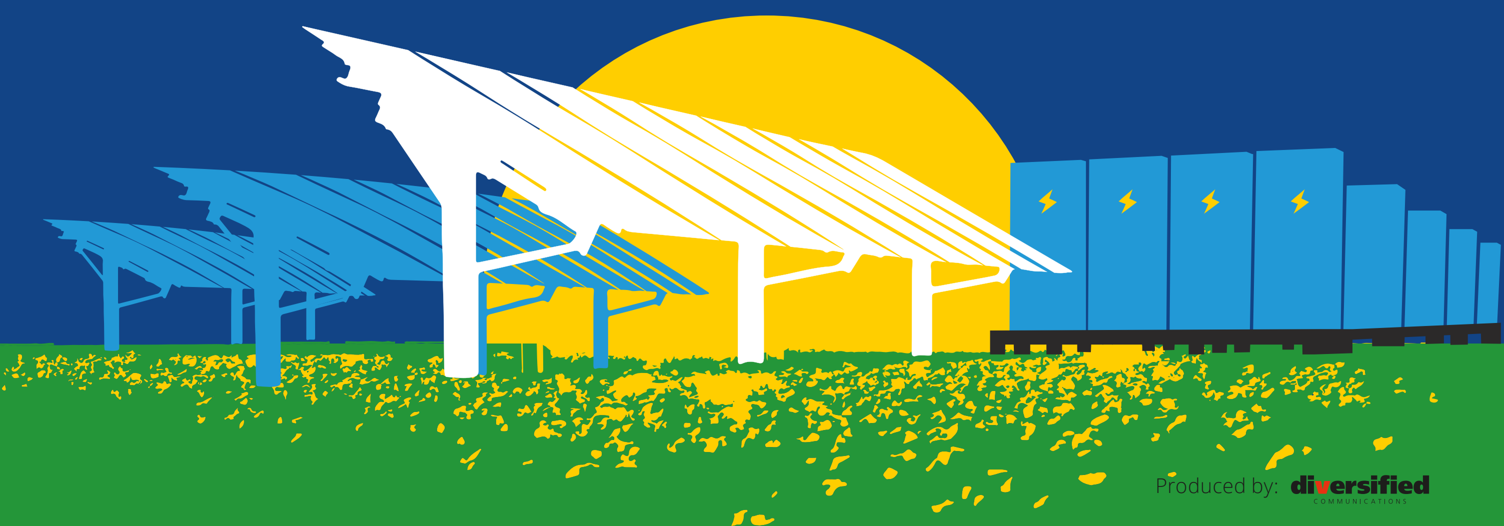

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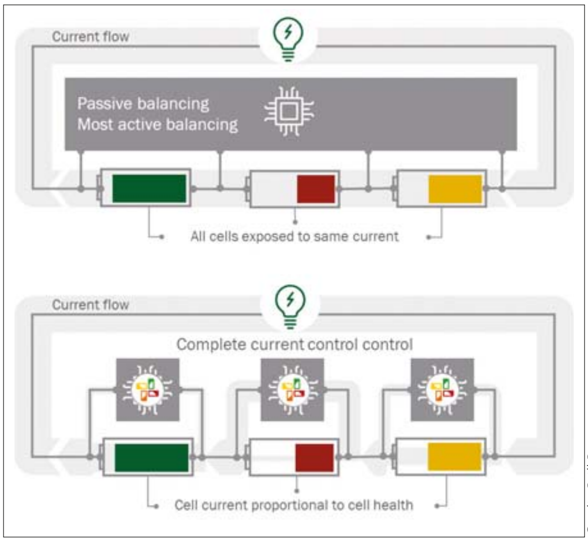
lead to de-rating of battery power or even safety issues. Moreover, energy is wasted during the charging process. The passive BMS can only monitor the pack current and interrupt it via a disconnect switch in the event of a fault. If bi-directional information flow is implemented, system-level parameters such as operational settings may be changed to prioritise either battery lifetime or performance. Lifetime is prioritised by reducing the operational window at the expense of available energy or power, while performance is prioritised by widening the operational window, at the expense of battery life.

Active balancing is typically implemented via low-current bypass circuits, which direct low charging currents to cells that are not yet charged, rather than dissipating the energy as heat. The main benefit of this approach is to improve charging efficiency, which may be important if the available charging energy must be utilised as efficiently as possible. For most applications, however, active balancing does not justify the added component cost for the benefits they yield. Like with passive balancing, cell degradation is accelerated by higher relative currents on weaker cells and hot spots may form.

Complete current control is a novel approach to battery control and management, recently developed and patented by our team at Brill Power, a spin-out company of Oxford University. The current on each super cell (or small super cell string) is continuously regulated in proportion to the health of the cells – weaker cells are exposed to lower currents, stronger cells to higher currents. This ensures that all available energy and power is utilised, no single cell or cell group limits the lifetime of the battery, and degradation on weaker cells is slowed down.

Safety benefits of complete current control include avoiding the formation of hot-spots by reducing the currents on cells with high resistance, and cell-level disconnects to contain any possible faults. This approach also has the benefit of system-level voltage regulation, which enables the direct integration of the battery with DC power sources, such as solar PV, fuel cells and other battery types, as well as with DC loads, such as EV chargers. The component cost of this approach is higher than for a passive balancing BMS, when the BMS is viewed in isolation, but lower when viewed at a system level.

The lower system cost is achieved by reducing battery size for a given performance and avoiding additional hardware such as DC/DC converters or inverters (which are needed to link solar PV and storage, or storage and EV charging). Total cost of ownership is reduced by extending battery lifetime by up to 60%, according to analyses by Brill Power and WSP.



Credit: Brill Power

A simplified illustration of different BMS types

Other, niche approaches to BMS technology include cascading cell bypasses and the integration of inverters, but we will not discuss them further here due to their limited applicability.

State estimation

Estimation of the State of Charge (SoC) and State of Health (SoH) is based on a combination of battery models and estimation algorithms. The level of sophistication and accuracy that is possible for state estimation and underlying battery models strongly depends on the hardware, which we use here to differentiate different approaches.

Integrated circuits (IC) are used in most conventional BMSs for state estimation, which are often referred to as 'fuel gauge'. ICs are 'hardwired' with chemistry-specific battery models and state estimation algorithms. The advantage of ICs is that they are low cost. The disadvantages include limited system design flexibility and accuracy. The latter tends to get worse over time. Design flexibility is limited because ICs are typically created for a particular battery chemistry with particular specifications.

If the battery chemistry or specifications change, the IC also needs to be changed and the design adapted. The reasons for the limited and deteriorating accuracy are (i) state estimation on ICs is based on generalised representations of the battery chemistry and doesn't capture the nuanced thermodynamic and dynamic properties of cells, which can vary between manufacturers, formats and batches, even for the same chemistry (ii) limited computing power on ICs constrains the complexity and fidelity of state estimation algorithms and underlying battery models, and (iii) cell characteristics change over time, which cannot be captured by hardwired IC algorithms, leading to increasing inaccuracy over time.

Microprocessors can be programmed with more complex, higher-fidelity battery models and state estimation algorithms, which can be fine-tuned to account for particular cell characteristics and specifications. The changing cell characteristics can be accommodated by updating the parameters of the state estimation algorithms and battery models, which keeps outputs more accurate over time. The same hardware can be used for any type of battery chemistry or manufacturer, allowing for ultimate design flexibility. The disadvantage can be higher component cost, depending on the required functionality and computational power.

Information flow

Uni-directional information flow is common in most battery systems: information flows from the BMS to higher-level systems and user interfaces. If the BMS is provided by the cell maker, less low-level information tends to be available, as this information can be considered sensitive. The most important information is safety and performance related and includes metrics such as SoC and SoH.

Bi-directional information flow is possible if the BMS can process inputs, such as changes to operational settings (for example maximal and minimal allowable cell voltage or SoC), or even updates to battery models or state estimation algorithms to maintain their accuracy, if microcontrollers are used.

Industry requirements

The selection of the appropriate BMS type is hugely important in creating the optimal battery system for a given application. However, all too often it is not up to the battery system manufacturers, developers or operators to select the appropriate BMS. The dominant cell manufacturers tend to impose their own BMS solutions for three obvious reasons:

- Revenues – can be increased by selling their own BMS
- Control and warranties – the BMS can be programmed with conservative settings,

not visible to the battery developer or user, that ensure that warranty cases are minimised. These settings may even be updated by the cell supplier or OEM over time to counter faster-than-expected degradation.

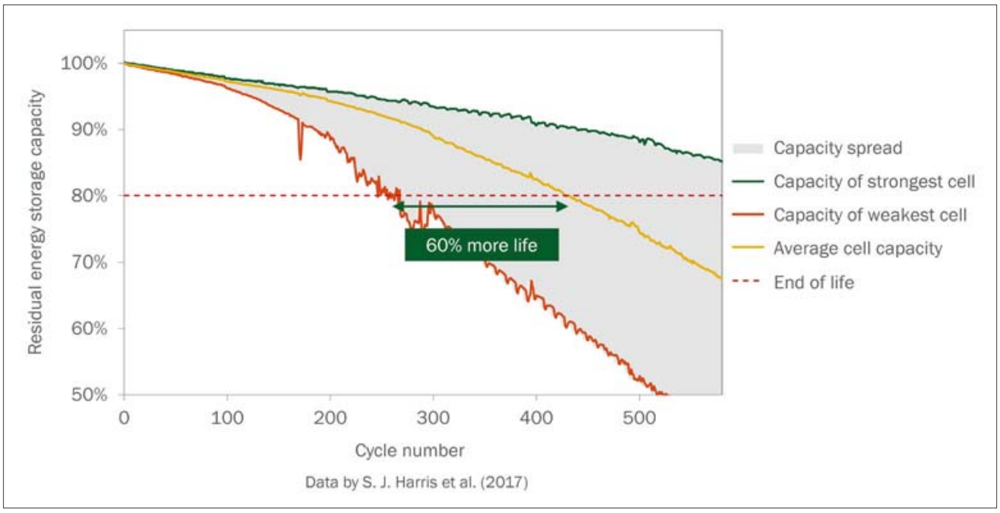
- Confidentiality – the BMS is the gatekeeper to cell-level data, which some cell manufacturers prefer not to make available to their customers.

The world's leading cell makers can take this approach because they control cell supply and can choose to not sell their cells without their own BMS. The preferred BMS approach of cell manufacturers is passive balancing with ICs for state estimation and unidirectional information, which can help undercut the competition on capex for battery modules and packs.

Cell manufacturers obviously strive to sell as many cells as possible, which means they are incentivised to limit battery lifetime to the minimal acceptable duration – a fact that must be considered when selecting integrated solutions of cells plus BMS from cell suppliers. Obvious advantages of this offering for battery system developers are the low capex of modules and packs, as well as the simplicity of purchasing fully integrated solutions. One suitable application for this BMS approach is backup power for businesses and industry, where cycle life is of little concern, provided that short to medium term warranties are sufficient.

A low-cost, low-functionality BMS may also be the preferred choice for energy storage deployments, which are scheduled to be augmented in the future once the system has lost too much capacity to operate. The rationale being future technology may be lower cost than today. The risks of this business model are that battery costs may not continue to decrease, not least because of bottlenecks in materials supply, the technical difficulties and 'unknowns' of integrating future and past battery technology, and additional maintenance cost due to high system complexity and downtime caused by failing battery modules or racks.

Suitable applications for active balancing are ones where charging energy is in short supply and must be used as efficiently as possible, such as solar power integrated onboard vehicles on land, air and sea. Active balancing may also be used for harvesting very small amounts of energy via small batteries for isolated systems in remote locations.



Credit: Brill Power

Growing concerns over the sustainability of batteries and their lifecycle, increasing knowledge of battery technology and system economics by developers and operators, as well as the fast pace of development in battery materials and chemistry are leading to increasing interest and demand for complete current control as a BMS approach. Applications that are particularly suitable for the complete current control BMS approach include ones that are sensitive to total cost of ownership or system capex, require high reliability and long cycle life, or that need particular flexibility regarding the integration of future battery chemistries. Examples include grid support with demanding use cases and high system cost, co-located solar and storage, storage projects needing to achieve lifespans of greater than 8-10 years, as well as mission-critical energy storage with maximal reliability.

The lifetime of the battery system can be improved if the battery is not limited by its weakest cell

BMS design and development

Once the appropriate BMS type has been identified, design and development can begin. The single most important factor in BMS design is the team and its expertise. Traditionally, BMS design has been the domain of electrical engineers, who are indeed best placed to design the circuitry, but don't typically have much knowledge of the inner workings of batteries. Designing the perfect BMS requires knowledge and expertise in electrochemistry, physics, electrical and electronic engineering, firmware development and data science.

With the right team in place, the first considerations should go to compliance with regulation and industry standards, since this has implications on both hardware and software design. Regulations and standards are typically specific to regions. Although most regulation and standards apply to the battery system as a whole, some regulations apply to all electronic components and includes hazardous substance regulation, such as the RoHS and REACH directives in Europe. Relevant industry standards strongly depend on application and system specifications. Typical differentiators are residential vs industrial energy storage, and low vs high voltage.

The most relevant standards for industrial storage include IEC62619, UL1973, UL9549 and VDE-AR-E 2510-50. Product and functional safety are the most important aspect of these standards. Although the BMS is not required to be certified as a stand-alone component, it must not prevent the battery system from being certified. Testing and evaluation of prospective standard compliance by independent test and certification organisations, such as DNV, is therefore highly recommended.

Hardware

Hardware design is heavily influenced by system-level specifications and requirements, which include battery module, pack and system specifications (such as current, voltage and capacity), system architecture (common dc link, load profiles, peak loads, peak charging currents), physical dimensions and resulting constraints, safety (thermal management, isolation, contactors), communication and connections. The above aspects inform BMS architecture (master/module arrangements, number of cells per modules and balancing connections), circuit board form factors, component selection, and interfaces.

These high-level specifications form the foundation for the development of electrical design concepts, which strongly depend on the selected approaches to balancing, state estimation and information flow. The simplest hardware design concepts can be realised for passive and some active balancing topologies, since virtually all complex components are available as off-the-shelf building blocks, including ICs for cell balancing and state estimation, which typically come with recommended balancing circuit topologies.

The only material differences in the various implementations of passive and most active balancing BMS designs are down to system-level specifications, such as system voltage and current, circuit board dimensions, communication requirements, and the number of cells that are balanced in each module (which is a segment of the battery pack).

The picture gets more complicated for some active balancing topologies and complete current control, since these concepts cannot be implemented purely with off-the-shelf building blocks and more sophisticated electrical designs are required. Some active balancing circuits require the integration and control of additional switches to bypass cells or cell groups. These switches interact with system-level control and balancing circuits and must be operated accordingly, which is primarily a firmware challenge.

Complete current control requires the integration of power electronics into the battery pack via a novel circuit topology that is capable of dynamically controlling the current on cells or cell groups in proportion to their state of health. This concept can be implemented with or without a voltage boost capability, meaning that cell voltage can be boosted by up two times the rated cell voltage.

Given the complex topology, new BMS designs are typically simulated as a first step to optimise system functionality and efficiency. Microcontrollers and MOSFETs are used at module-level to implement both state estimation and resulting dynamic current control. Complete current control ensures that cells are continuously balanced, meaning that no separate balancing circuit or balancing step is required. Communication channels between modules are important for this approach due to the speed and amount of data required to flow between modules. Brill Power's patent pending communications bus offers a low cost, low-complexity solution to this challenge by replacing separate communication links to each battery module with one communication bus.

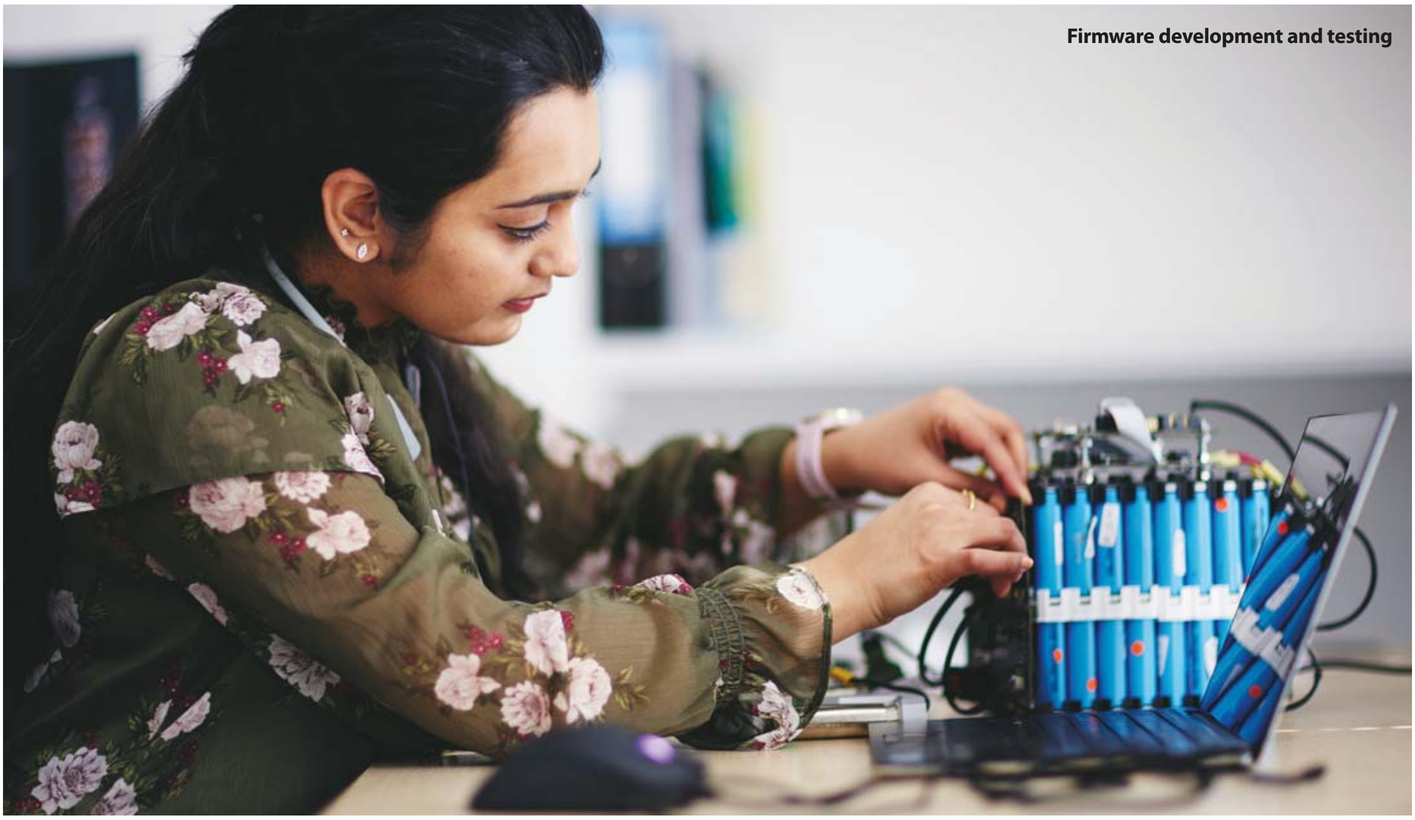
Software

The BMS relies on and interacts with various types of software, which can be broadly categorised into on-board software (embedded on the BMS hardware) and off-line software (hosted on computers and servers that interact intermittently with the BMS).

Embedded software includes algorithms for state estimation (such as battery models and estimation algorithms) and balancing, as well as safety settings, which typically initiate safe shutdown procedures when triggered. Safety settings depend on the battery chemistry and manufacturer specifications and are either 'hardwired' on ICs or set when using microcontrollers.

Accurate measures of SoC and SoH are not only important to establish what the battery can and cannot do at any given point in time, but also to determine whether any warranty conditions have been triggered. Since the SoC and SoH of battery cells cannot be measured directly, mathematical models are needed to calculate them based on the parameters that can be measured, including voltage, current and temperature. These models and measurements are never perfectly accurate, which is why they need to be combined with so-called estimation algorithms that continuously compare the model outputs with measurable quantities (typically voltage), using the computed errors to adjust model outputs and improve the accuracy of SoC and SoH estimates.

The two greatest challenges in producing accurate SoC and SoH estimates are



Firmware development and testing

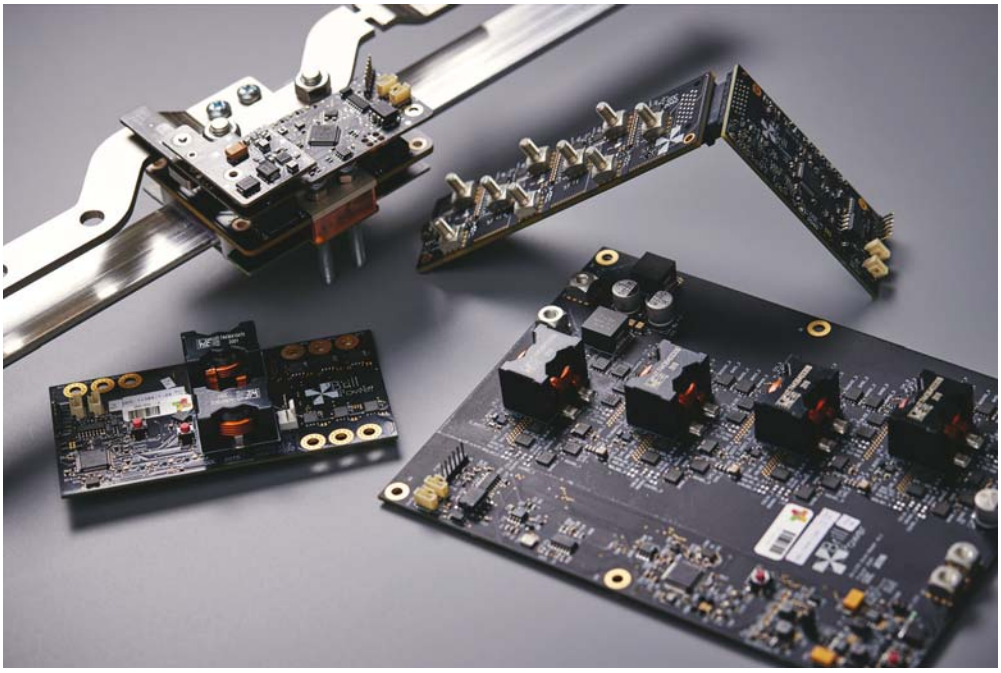
Credit: Brill Power

(i) battery behaviour can vary significantly between different manufacturers and formats, even if the chemistry is the same, and (ii) battery behaviour changes over time and models become increasingly inaccurate if they are not updated. These challenges are mainly a concern if ICs are used, which are 'hardwired' with representative battery models and don't adjust the models over time. When using microcontrollers, battery models can be adjusted to accurately represent the exact cell in use by extracting the model parameters from cell test data. These parameters can be updated throughout the lifetime of the battery to ensure continued accuracy.

Cell balancing algorithms for passive and most active balancing BMS types simply determine upper cell voltage limits and trigger the balancing circuit switches, until all cells have reached the same voltage. Complete current control incorporates cell balancing in its main current control algorithm – charge and discharge cell currents are proportional to SoC and SoH such that all cells are continuously balanced.

Off-line software that may interact with the BMS includes battery monitoring, analytic and predictive software, which helps the user keep the battery safe, flag any faults, determine important performance characteristics (such as available energy and power), schedule any maintenance, estimate the remaining useful lifetime, and even determine residual asset value of the battery system.

At a minimum, the BMS must pass high-level information to off-line software programmes, such as SoC, SoH, battery voltage, current and temperature, which is then displayed to the user and, potentially, used to perform more complex computations to anticipate pending faults, determine how much battery life is left and how are performance characteristics likely to change (in case this is not computed onboard the BMS). More sophisticated embedded BMS software may be able to take inputs from offline software, such as adjusted operating limits and battery model parameters. Clever utilisation of offline software can increase the overall computational power available to optimise battery operation, as well as to minimise component cost by reducing the computational load onboard the BMS itself.



Credit: Brill Power

Future trends

As with any technology, it is very difficult to predict the course or timescale of developments in BMS technology. However, a few macro trends in the battery industry are likely to influence the choice of BMS technology and its future developments.

- **Sustainability**

Increasing awareness and concerns about environmental and social impacts of the manufacture of battery technology is already influencing expectations regarding battery quality and life cycle. Therefore, BMS technology capable of maximising battery lifetime and minimising battery waste will likely grow in popularity.

- **Co-location with solar and wind**

Energy storage is increasingly co-located with solar and wind power projects to reduce local effects of intermittency of renewables and to maximise system efficiency. Batteries used for such applications will be expected to reach the same lifespan as solar PV and wind turbines. BMS technology that can maximise lifetime while minimising system complexity and lifetime cost will be favourable for such projects.

- **Future-proofing of storage**

Battery technology changes rapidly; new cell products are introduced every year and entirely new chemistries are under development, such as sodium-ion and solid-state batteries. For developers of battery systems, it is important to be able to quickly adapt to new chemistries, which is enabled by a flexible BMS approach. The same argument holds for energy storage projects that are scheduled for augmentation with future technology, which must be compatible with older batteries.

- **Product differentiation**

The battery cell and system market is dominated by a small number of high-volume manufacturers, whose low cell and pack costs can undercut most smaller developers and manufacturers of battery systems. BMS technology can be used by the smaller players to gain a competitive edge in product quality and lifetime.

Unlike innovation in battery cells, BMS technology does not rely on fundamental scientific advances, and can bring step-change improvements to today's battery technology. The innovation potential in BMS technology has been largely overlooked in battery system development but we believe it will play a crucial role in the battery systems of the future. ■

Authors

Christoph Birkl, DPhil, CEO and co-founder of Brill Power, has seven years' experience in battery and fuel cell R&D and was recipient of the Royal Academy of Engineering's SME Leaders Programme.

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