pv magazine energy storage+

February 2018

ENERGY STORAGE HIGHLIGHTS

Business models beyond frequency regulation
Redox flow vs. lithium-ion | Flexible sector coupling

Special edition in collaboration with ENERGY® STORAGE EUROPE


Photo: Younicos


Photo: Anesco

Contents

Flexible sector coupling

Fuhs: We are happy that in cooperation with Energy Storage Europe we can present this energy storage special edition. For us at **pv magazine** it is a step to even more detailed coverage of energy storage and related topics on all of our platforms.

Mingers: And for us, the new issue fits perfectly with the strategy that we pursue with all trade fairs. Not only do we see ourselves as a pure organizer, but we always try to promote the development of the industry. And of course, that includes sound reporting. For the storage industry, I hope the market's development will align with Bloomberg New Energy Finance's forecasts, and that by 2030 the global market will have doubled six times.

Fuhs: The outlook is good, and we are seeing how new business models evolve. We ran a roundtable with analysts and industry experts, discussing among other things the business models that can contribute to this tremendous growth. Large-scale storage for frequency regulation will not be sufficient to drive this kind of growth. All participants agreed that there is a lot going on with business models beyond frequency regulation right now. They were also all surprised by how the combination of storage with utility-scale photovoltaic systems developed over the past year.

Mingers: That is also a very interesting development for me. In any case, our team is very excited about seeing what will prevail in the coming years, and how the models can be combined, especially in the utility-scale segment. This segment has always played an important role for our exhibitors because they show many solutions that are currently being used to store large amounts of energy.

Fuhs: In the special edition we have included, among other things, top new technologies submitted by exhibitors at Energy Storage Europe, evaluated by five well-known experts. The experts did not take a uniform approach to assessing these technologies. Some made the uniqueness of the innovation the guiding criterion. Others, whether a company has presented a clear business model in its submission. Others still have prioritized the company's prospects based on their market power, whether it comes from having a good track record or a particularly strong financial footing.

Mingers: And what was most convincing for you?

Fuhs: The evaluation criteria show that there are different winners depending on the approach, and how varied interests can be. The trade fair visitors will also be very diversified. We looked in detail at this issue, both at products that at first glance look very standard, such as storage

Bastian Mingers
Executive Team Manager
Energy Storage Europe

a key driver

containers, and at innovations which still appear further away from the market, such as redox flow batteries. You have to go deeply into the details, then you will find the differences between the offerings and concepts. I found that very interesting. The top 10 submissions will now be candidates for our **pv magazine** Award, which we will give at the end of the year.

Michael Fuhs
Editorial Director **pv magazine**

Mingers: I am fascinated by the speed with which sector coupling is currently developing, while at the same time being the subject of much controversy. One controvery for example is the actual speed with which sector coupling is brought forward. Until recently, everyone has done their own thing: those who develop power-to-gas or those that develop electric mobility, for example. Then there were those who felt energy storage was more important than expanding grid infrastructure and vice versa. Fortunately, this has changed. For example, at Energy Storage exhibitions and conferences various stakeholders now meet to bring these strings together. In addition, the energy transition in the heating sector can play an increasingly important role, and thus also thermal storage.

Fuhs: What impact do you see on the individual storage technologies?

Mingers: The complexity of the different storage technologies is strengthened by the fact that the industry is now intensively involved in sector coupling, which is simply great to see. This leads to flexible sector interconnection, which will play a major role in the conference program. Flexible sector coupling acts as a fundamental driver for the deployment of energy storage.

Fuhs: At least if the sector coupling is combined with renewable generation. Here you also see the complexity of the technological solutions being deployed. In the magazine, we report on two interesting projects in the field, which open up completely new perspectives. Speaking of flexible sector coupling, it has been more of a conference theme so far, and now you emphasize its importance in the exhibition. In general, the importance of the exhibition compared to the early years of Energy Storage Europe seems to have increased. Is that so?

Mingers: The Energy Storage Europe Conference is, so to speak, the link between the fundamental work of scientific innovation and the market-ready products that will be exhibited at the trade fair. This is the classic evolution of a conference toward a trade fair. The conference is the foundation, the fair brings the leading experts, suppliers, and users together.

Debrief: 4 key questions

Storage trends: In the run-up to Energy Storage Europe, pv magazine asked industry experts the key storage topics they were most interested in. Their responses were reflective of their own perspective and position throughout the value chain, but nevertheless a theme emerged, with recurring questions arising over and over again. These were those questions …

1. Which business models for medium and large-scale beyond frequency regulation are evolving?

Perhaps the greatest surprise to emerge last year was the combination of large utility-scale solar power plants and storage systems. All of the experts included on the **pv magazine** panel were surprised by the alacrity at which this co-location business model grew (see p. 24 for a deeper analysis and p. 27 for the panel discussion). One story above all appeared to shake the industry, and that was the prices communicated in the solar + storage bids for tenders at Xcel's project in Colorado, USA. The median price struck was $0.036/kWh. However, this number should not be overstated because the bids are at a very early stage, and it is not yet known just how much storage capacity the bidders have provided. Such bids should be seen more as a basis for negotiation, rather than binding offers. Nevertheless, our experts agree that this result is an excellent indication that the solar and storage industry is moving in an exciting direction.

The market for C&I storage is especially large and dynamic in the U.S. Such bullishness and optimism cannot necessarily be applied yet to other countries, because much depends on the tariff structure.

Storage peaker plants are more typical in the U.S. or the U.K. than in continental Europe. A gas peaker plant typically has a single digit capacity factor, i.e. it is running for a short time only during a year – when the load in the grid is particularly high. Some markets, such as the U.K., have capacity auctions where they specifically take bids for capacity, says Logan Goldie-Scot, analyst at Bloomberg New Energy Finance (BNEF) in San Francisco. Other markets are energy only, where it is assumed that for a certain time of year during the greatest peaks in demand, energy prices will be just high enough to justify keeping a power plant operational to meet those peaks.

Photo: Neoen

Australia's 100 MW/129 MWh Hornsdale Power Reserve facility was delivered by Tesla and shows how business models beyond frequency regulation grow.

Storage successfully participated in a capacity auction in the U.K. winning 0.5 GW for delivery in 2020/21. In California, this business model already appears successful. According to Goldie-Scot, roughly 280 MWh capacity was commissioned in December 2016 and January 2017 to respond to the potential shortage of gas caused by the devastating leak and subsequent shutdown of the Aliso Canyon gas storage plant. One reason for regulators to pursue storage is that it can be used to help hit their renewable energy targets by shifting renewable generation to later in the day, says Goldie-Scot.

In 2016, the analyst came to the conclusion that globally approximately 390 GWh/170 GW purpose-built battery peaker plants could be feasibly commissioned. A very interesting take on this is to ask whether behind-the-meter-storage can take a slice of the cake. If incentivized to do so, this would save some $100 billion in capex, primarily because behind-the-meter-storage is being built for other purposes and often paid for by consumers eager to reduce their electricity bills. "Aggregation payments would not necessarily have to cover the total cost of the system, but could instead be partial and additive," Goldie Scot suggests.

One of the big questions during the panel discussion was why do the most effective business models differ from region to region? It could be because grids are developed differently and generation and load profiles are different. It could also be simply down to a different political approach. Ravi Manghani, Director of Energy Storage at GTM Research, says, "The important fact is that the energy transition is beyond just centralized infrastructure." One way to deal with the energy transition is to use it to develop new business models that also serve the power system, which the panel sees more in the U.S. and U.K. than in continental Europe. But there is also

facing the storage industry

movement in Germany, for example with applications of larger storage systems in the distribution network (p. 12).

2. What does the raw material supply for lithium-ion batteries on the one hand and the technical development of other storage technologies on the other hand mean for the choice of technology?
There is no clear answer to this question, which is probably why it is asked so often and so widely. Pure cobalt resources could last for 500 years, and lithium for 440 years. However, it is accepted that such a viewpoint is simplified because the impact of resource availability depends on the price at which these reserves can be mined. On the other hand, it is also known from coal, gas, and oil production that progress is immense and the price at least does not rise – resource availability regularly exceeds what was forecast. Recycling is also gathering speed. Cobalt can be recovered to over 90%. Lithium, however, is barely recycled currently, but there are developments in the pipeline and a 70% recycling rate seems possible. We have therefore titled the article on the subject as: "Do not worry, but keep asking" (p. 18).

"Don't worry" also applies to the development of new technologies. A recent calculation by Apricum shows that redox flow can compete with lithium-ion technologies for storage durations of more than three to four hours (p. 23). At least as an alternative, this technology is disposable, even if there are challenges in securing financing. Nevertheless, large projects are already being planned, such as huge storage in salt caverns in Northern Germany. It will take some time for the developments to accelerate, and it will also depend on the development of lithium costs. Even with lithium-ion batteries, progress has not paused, and developments in the coming years will also allow for batteries with reduced cobalt.

Taken together, considerations on raw material and technological development can be concluded as follows: "The decade to 2025 is the decade of lithium-ion," so said Matthias Leuthold from RES during the panel discussion.

3. What are the key innovations that will affect the market for medium and large storage systems?
Large storage container solutions are certainly vital here. Two companies submitted their solutions to the highlights feature (p. 7). It is worth considering how the technical specifications play a role, including the control speed, which, for example, highlights SMA as a USP because synchronous generators can only be completely replaced when the reaction time of the storage system to grid characteristics is extremely fast. On the other hand, of course, the positioning of the company is important for the impact of a product. Fluence, which brings together AES and Siemens, is very well positioned, according to BNEF. AES owns many distribution utilities globally and is a large independent power producer. This allows Siemens to benefit from the operational experience of its new partner. Another powerful storage application is the combination of battery storage with gas turbines submitted by Siemens, Younicos, and Bosch. These solve the problem brought by lithium-ion batteries, namely that the capacity is costly. Then again, it no longer pays to run gas turbines continuously.

There are also interesting developments where companies are pursuing entirely new approaches. Much still remains to be seen how effective these will prove. For example, Max Bögl combines wind power and pumped hydro storage. Schmid combines electric charging stations with redox flow storage systems. Electrochaea participates in the power-to-gas technologies with a promising methanation concept, and Nel Hydrogen with the combination of solar power plants and hydrogen production. However, few can accurately predict how much the energy industry will rely on methane or hydrogen in the future. For most experts it is clear: This topic will become relevant in large scale only from about 2030 onwards. The technologies, though, have to be developed right now.

4. What is the prospective for European cell production?
Industry voices all say that they want a high volume production of battery cells in Europe. But the development landscape is still tough. Germany-based consortium TerraE plans to build a 6 gigawatt-hour factory soon, with considerably more capacity out to a 2027 time frame. However, so far only €17 million in funds have been communicated, which is a relatively anemic amount that is unlikely to drive any great technological leaps. The 2027 goal is, cautiously speaking, unambitious in such a highly dynamic market. In the U.K. rather more generous sums are being spent. Some €300 million will be distributed to leading universities to boost R&D efforts and help accelerate commercialization and cell industry problem-solving. However, while laudable, both programs target research institutions, with little immediate cash earmarked for production. Northvolt, a Swedish startup that wants to build a 32 gigawatt-hour production by 2023, is setting its sights higher: to €4 billion to be exact. Volkswagen Scania and ABB have already invested relatively modest sums, and it is not yet known whether the company has raised more than tens of millions of euros. In conclusion, there are plenty of recent developments, but it is still necessary for commercial entities to actually take action, and investment, into their own hands.

Ian Clover, Michael Fuhs

Energy storage highlights

Ranking: At the Energy Storage Europe trade fair in Düsseldorf, 24 exhibitors submitted proposals that our highlight jury ranked in the following categories: relevance to industry, USP, market impact, contribution to energy transition, and innovation. Here, we present the top 10, as chosen by our experts.

The submissions of exhibitors at Energy Storage Europe for the first pv magazine highlights feature in 2018 are drawn from a collection of very different approaches. So it is not surprising that the five jurors judged things differently. In the end, every juror had their own top candidate: SMA, Fluence, Max Bögl, Younicos, and electrochaea were all selected in the top position of one juror respectively. After averaging the votes, all of them finished among the top 10, except for Fluence. The two main arguments that the judges used to evaluate are simple: One part was focused on the foreseeable success of the product, concept, or project as well as the market position of the company. Other members of the jury placed higher emphasis on innovation, potential for disruption, and the chance to change the market in a sustainable way.

That such a chance will materialize is not always a given. Among the submissions are, for example, the wind turbine of Max Bögl with a water reservoir built into the foundation that is part of a hydro storage power plant; and Jena Batteries, with a redox flow battery utilizing organic electrolytes that are environmentally sound, and possibly cheaper than conventional electrolytes based on vanadium. Both concepts have yet to prove their competitiveness. There are also some submissions where the USP is not immediately clear, but some jurors nevertheless expect to be successful: For example the storage containers from SMA and Fluence. The jurors also highlighted the extent to which a submission served an important market segment, such as Younicos's combination of a battery with a used gas turbine. Incidentally, Siemens and Bosch also submitted similar combinations.

In this highlights feature, we present in detail those submissions that made it into the top 10 (10th place is shared, and all other entries are listed on page 14). Those that did not make the top 10 are certainly worth a mention and visit at the trade fair: Aside from Fluence, for example, Schmid was also highly rated. The company from southern Germany has developed a carport with several electric filling stations and integrated redox flow storage. If many cars refuel at the same time, the storage buffers the load so that the grid does not need to be reinforced so much. This is flexible sector coupling, and one of the most important current developments (see p. 16).

The top 10 submissions will automatically be **candidates for the pv magazine award 2018**. This will be awarded at the end of the year along with the submissions we will be looking at throughout the year, and will be evaluated overall on various highlight categories.

Highlights Jury

Logan Goldie Scot heads up the Energy Storage insight team at Bloomberg New Energy Finance. He leads the company's analysis on the global energy storage markets, providing insights on technology, markets, policies and regulation, and the competitive landscape.

Tobias Federico is the Founder and Managing Director of consulting institute Energy Brainpool. He is a proven expert on the energy market, and on price forecasts in Germany. He actively monitors the introduction of new technologies such as blockchain.

Dirk Uwe Sauer is Professor of Electrochemical Energy Conversion and Storage Systems Engineering at RWTH Aachen University, and one of Germany's foremost experts on energy storage issues.

Julian Jansen is a Senior Market Analyst at IHS Markit Technology. He focuses on battery storage market activity and industry trends, as well as analyzing key value drivers and emerging business models driving storage deployment. Additionally, Julian provides high level consultancy and strategic advice for bespoke projects.

Stephan Schnez is Senior Scientist in Corporate Research at ABB in Switzerland. As a physicist, he works in the field of energy storage and systems. He also regularly assists ABB management and technology ventures with questions regarding the assessment of potential future technologies.

1

Younicos

Combined gas and battery grid services power plant

Photo: Younicos

Younicos managed to interest and convince the jurors with its simple concept. Their rankings ranged from first to 16th, and so for the average overall juror rankings and proposals, this led to the top position in this highlights feature. Younicos submitted a project in which the company, together with the Technische Werke Ludwigshafen, developed a combined balancing power plant, coupling a 4 MW gas turbine with a 9 MW battery with a capacity of 6.5 MWh. The intention is to provide both primary and secondary control power, and to get prequalification from the network operator for both installations as one technical unit. The plant is still under construction. The left side of the building in the photo above is intended for the battery, the right for the gas turbine.

The combination will serve an often-overlooked market segment with significant scaling potential, says juror Julian Jansen. "Younicos has successfully shown how to do a hybrid solution which can provide a range of balancing services and is predestined to effectively stack multiple values," says Jansen.

There are many small-scale, partly older gas turbines in operation – 250 with under 15 MW of power in Germany alone. Their long-term operation is often no longer worthwhile. One reason is that they can only offer balancing power if they are up and running, otherwise their reaction time is too slow.

At the same time, the demand for balancing power is rising as part of the energy transition. For battery storage to be able to offer this alone it must be equipped with a lot of storage capacity. The charm of the solution presented is that within this technical unit the gas turbine does not have to run continuously, but the battery initially takes over, and the gas turbine only intervenes when the duration of the control power exceeds the capacity of the battery.

It is therefore an interesting "second life" project for gas turbines in the given combination, says juror Tobias Federico.

However, as with most business models, there is also competition. As the market for primary balancing power is relatively limited, the option of achieving the conditions for the secondary balancing power market is interesting, notes another member of the jury. With this business model, however, the combined gas and battery storage power plant is competing with intelligent demand-side management.

One of the categories for the highlight ranking is its relevance for the energy transition. For the combined gas and battery plant, this is the case because it reduces the so-called must-run capacity of conventional power plants. How relevant the topic is can also be seen by the fact that Siemens and Bosch have also submitted highlights that deal with the connection of battery storage systems with conventional generators.

Hall 8b / D02

2

E3/DC

Multi-string three-phase battery inverter technology

Photos: E3/DC

Highly rated by several of the jurors, E3/DC made it into second place overall. If you look at the individual highlight categories, the manufacturer of small and medium-sized storage systems scored particularly high for innovation.

The company, already well known for its residential storage system, has submitted a new technology for a DC-DC converter for battery storage systems, with which users can better control the state of charge. This is especially important for emergency power systems.

In addition, the power electronics have a high discharge capacity with efficiency of up to 98%, even if you connect 48 volt battery modules. This allows a C-rate of 1 and a maximum output current of 120 amps. According to E3/DC, the trick is a new topology with galvanic isolation and an ultra-high frequency allowing for small components. The inverter will be used in the 12 kW battery systems of the company.

The challenge for the innovative state-of-charge-control is that no lithium battery system can have an accurate state of charge measurement without being discharged and charged from time to time, states the company. If you measure the state of charge in this way, the battery may be empty in an emergency. The solution is to operate two battery modules asymmetrically. As one is discharged, the other holds a defined state of energy.

The comments in the jury on the product are varied. One juror sees technical innovation, but is not sure about the business relevance. Another is not sure about the USP, but places emphasis on the strong contribution to the energy transition.

Hall 8b / E22

3

SMA

Large-scale storage solution

Photo: SMA

In 2017, SMA introduced its large-scale turnkey solution Medium Voltage Power Station to the global market, and now the company reports it has concluded contracts with a total capacity of 400 MW. One container has an output power of 5.5 MW.

Unique to this solution is that the Sunny Central Storage with grid forming capacities acts just like a rotating mass in a power grid, writes the company in its submission to **pv magazine** highlights. There is a distribution of responsibility between Grid Controller and Sunny Central Storage.

Energy flows and general operational tasks that take place within a few hundred milliseconds to seconds or even hours are carried out on the Grid Controller, while functions regarding grid stability that need reaction within milliseconds or less are located in Sunny Central Storage, directly avoiding any communication to fulfill these tasks.

The technology mimics the function of rotating mass in the grid to load and subsequent frequency changes. When load increases, rotating masses are decelerated, but their inertia dampens the effect until the generator power is increased.

While the jurors generally doubt that the solution is as unique as the company claims, most acknowledge other strengths of the product. One juror emphasizes it's importance in grid connected installations to reduce the share of conventional power plants, which today guarantee the frequency stability with their rotating masses. Another emphasizes the pure size, i.e. the 5.5 MW power output of these devices, the long track record of SMA in this field, and the contribution of the company to bring down costs.

"Out of all the entries SMA has probably submitted the most commercially advanced offer, rather than a technical innovation", says juror Julian Jansen of IHS. "Building on their strength in the power conversion system market, SMA has used the experience to build a turnkey solution which can target multiple applications and seamlessly integrates into existing infrastructure."

SMA has deployed the system in places such as the island St. Eustachius in Netherlands Antilles. The first step was a fuel saving system. In 2017 it was complemented with the new inverter and battery system, which is now available "off the shelf" (see photo above). PV penetration now can now reach 100% during the day, says the company.

Volker Wachenfeld of SMA is convinced of the uniqueness of the product. "We supplied island-ready battery inverters, PV inverters, batteries, medium voltage connection, the power management system with the interface to the generators, and the SCADA", he explains.

He goes on, "We regulate the load balancing, create a seamless transfer at diesel shutdown, provide instantaneous reserve, and primary and secondary control power."

Typical systems for primary control power need several hundred milliseconds to send the command to the responding units. "We can initiate a reaction within the time of a half wave," he says, which corresponds to about 10 ms. This reaction time has to be adjusted according to the characteristics of the individual grid in order to guarantee the security of the supply, also when load in the grid changes quickly.

Hall 8b / B22

4

Fraunhofer ISE

Power electronics for battery inverters


Photo: Fraunhofer ISE

According to Fraunhofer ISE, the Cell-Booster and the power electronics for the project "Netefficient" permit high efficiencies on the one hand, and small construction volumes on the other. The cell booster converts the typical 48 volt output of a low voltage battery with an efficiency of 97% to 700 volts, as required for example by a three-phase battery inverter. According to Stephan Liese, Head of Group Distributed Generation and Storage, the key factor enabling this high efficiency is the high frequency with which the transformer is operated and which is even modulated. According to Liese, efficiency levels of between 90 and 95% are customary in the market for comparable applications. In addition to the increased efficiency, the high frequency also helps to reduce the size of the housing.

For the Netefficient project, which aims to increase the share of renewable energies on the North Sea island of Borkum, the institute has built a 1 MW battery inverter.

This is characterized by the use of silicon carbide MOSFET switches, which leads to high efficiencies of up to 98.5% and at the same time allows the volume to be kept small. The electronics for 1 MW output power fit into a standard 19 inch switch cabinet.

The jury found the submission very interesting from a technological point of view. "Currently, inverters in stationary applications cause around twice as much loss as the lithium-ion batteries themselves," writes one juror. "Therefore, efficiencies are of such high relevance." He also sees Fraunhofer ISE's ability to bring the technology to market together with industrial partners. Two jurors are missing that they have not found a concept for the market launch. One of the jurors asks whether the large number of components would lead to higher costs.

Hall 8b / B39

5

Electrochaea

Scalable Methanation plant

You would be forgiven for not knowing of methanothermobacter thermautotrophicus – a small green bacterium – but it is the basis of this energy storage highlight. Electrochaea uses it to convert hydrogen to methane. With this submission it reaches first position in the categories innovation and contribution to the energy transition, which together lead to fifth position overall.

The company uses a variant of the bacterium, named archeva (see right photo), as a biocatalyst, which is exclusively licensed from the University of Chicago. It developed the technology to a state that it can be used in large methanation facilities and the first demonstration plant is running near Copenhagen with 1 MW electrical power (see left photo). The efficiency of the methanation exceeded 80%, writes Electrochaea in its submission. The plant has demonstrated, according to the company, that the technology can be "quickly" scaled to the 100 MW range.

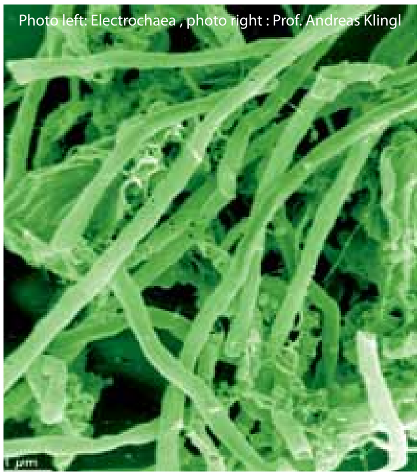


Photo left: Electrochaea , photo right : Prof. Andreas Klingl

One of the questions is whether it is necessary to convert the hydrogen to methane, or whether the hydrogen should be stored directly. Biomethane has the advantage that it can be used without limitation or expensive investment in the existing natural gas grid. Therefore, Electrochaea sees Power-To-Hydrogen as a supplier technology for methanation, rather than a direct competitor.

"Power-to-gas will become one of the crucial aspects in the energy transition," says Tobias Federico. "It is necessary to build it in large scale." Other members of the jury also see the innovation, but are not convinced that power-to-gas technologies will become relevant in large-scale in the near future, but only after 2030. Low temperature processes and fast reaction times might be helpful for the implementation of the technology, which might be an advantage compared to other methanation concepts, and the use of microorganisms may be a major innovation in this sector.

Hall 8b / D12

6

Smart Power

Large-scale storage business model in the distribution grid

German EPC Smart Power is working on a promising solution for making large-scale storage systems usable in the distribution grid despite regulatory hurdles. According to the numbers given by the company, this approach can totally make sense. The utility Stadtwerke Trostberg Energieversorgung is charged €113/kW peak load at the transformer station to the 110 kV grid. By peak shaving in the distribution grid in the order of 11%, this payment can be reduced.

For this purpose, Smart Power is installing a 1.5 MWh/1.2 MW storage system on behalf of a retail company. An annual revenue stream of about €59,000 is expected from the peak shaving use case, and an additional €89,000 will be generated from being active on the primary control market.

The tricky point, however, is compensation. The utility compensates 80% of the amount it saves from the peak shaving activity, and 20% will be used to reduce grid surcharge on the electricity bills for consumers in the region. The utility itself cannot draw direct financial benefits from this project because of German regulations. The cooperation is partly driven by idealism, and partly because the trading division of the utility is in favor of it, as it can offer good services to the operating retail company, which is its customer.

The theoretical upper bound for the revenue stream can be calculated as follows: €113 × 1,200 kW × 80% = €108,000. The real peak load reduction is roughly half of this upper bound value. To achieve this revenue peak shaving is necessary only for some weeks of the year. And by pooling several storage systems, the losses from peak shaving for the primary control power revenue stream can be reduced to a single digit percentage.

The jury appreciates the effort to make use of the possibilities storage offers for the distribution networks. However, they say, many other companies already are, or soon will be aiming for multiple revenue streams, so it is not possible to establish a USP with such business models.

Also how well this business model complies with German regulation is still to be proven. There is an intensive ongoing discussion about what is possible and what should be possible. Only by undertaking such projects can one move forward and develop the details. The company emphasizes that the installation is not simply a demonstration project, and that it is planned to be profitable without any subsidies.

Hall 8b / E13

7

Abo Wind

Storage in rural distribution networks stabilized the grid

Tunduma, a small Tanzanian town at the border with Zambia, is connected to a 220 kV transmission grid. The grid is characterized, writes Abo Wind, by "large distribution networks at 33 kV supplying thousands of small transformers." The overhead lines are working at maximum capacity, leading to high losses and a drop in voltage of almost 20%. Abo Wind has evaluated how the grid can be stabilized using solar and storage. Now it is in the development stage of a project to realize this potential. The installation will stabilize the voltage level in the 33 kV radial distribution networks between 95% and 105%. This will allow more consumers to be connected and SMEs to profit from better grid quality and fewer blackouts. Typically, the maximum load in Tunduma is about 7 MW in the evening. With the projected PV and battery size, which during the day is charged with about 5 MWh, the maximum load can be reduced to about 6 MW.

The company writes that there have been studies for similar projects, however, they haven't heard of any as far advanced. "Not conceptually new, but a straightforward use of batteries with 'smart' power electronics and control," comments one member of the jury.

Hall 8b / D39

8

Wemag

10 MW-storage plant with black start capability

Northern German utility Wemag made headlines several years ago with what was then the largest battery storage power plant in the country. In 2014, 5 MW went online for marketing in the primary control energy market. In 2017, this battery storage power value was extended to 14 MW and made black start capable. Now it has a capacity of 15 MWh, and provides control capacity comparable to that of a 100 MW gas turbine. The company emphasizes that the extension was not subsidized, but for the black start ability, a state subsidy of €180,000 was paid. Wemag now wants to offer its expertise in construction, operation, and marketing to other interested parties. Tobias Federico says, “These are innovative projects, due to the fact that they have taken the financial first mover advantage.” However, the jurors note that primary control power plants and black start capability are no longer particularly innovative. They also talk about how the primary reserve power market is evolving in the face of the huge buildup in battery storage capacity.

Hall 8b / C01

9

Fronius

Adjustable water heater with further functionality

Photos: Fronius

A solution that allows homeowners to use excess solar power via a heating element does not seem like big news at first glance. Such devices have been available for some years, controlling residential rooftop solar so that no current flows into the grid, but surplus is used to warm up the hot water boiler with a heating rod.

According to Fronius, the special feature of the device is that beside the necessary function – heating the hot water boiler – it also includes more features than usual: It includes comprehensive monitoring, can be networked via WiFi, LAN, or RS 485, works in combination with other heating elements, and above all is steplessly controlled. The single-phase device has a power of between 0 and 3 kW, the three-phase device between 0 and 9 kW, and both comply with the guidelines for electromagnetic compatibility. Minimum and maximum temperatures can be defined, and depending on the setting, the device heats up to over 60 °C for Legionella (pathogenic bacteria) prevention in the time intervals set, even if there is no excess of solar power. With appropriate dimensioning of the solar system, conventional heating can be completely switched off during warmer months, so that the hot water is obtained only by the heating rod, writes the company in its submission.

The response from members of the jury was as follows: It is a relatively straightforward product, and while it does not require any major innovation, the described functionality and market position of the company is convincing. One juror notes: "Integrated home energy supply systems, in particular with the integration of heating systems with PV, will play a central role. Therefore, the product is definitely going in an important direction."

Hall 8b / C18

Highlights rank 12 to 24 and more

- 12 **Schmid Energy Systems:** Charging station with PV and redox flow battery — Hall 8b / B24
- 13 **NEL Hydrogen Electrolyser:** Large-scale hydrogen production from PV power plants — Hall 8b / B11
- 14 **Commeo:** Energy storage — Hall , 8b / D01
- 15 **Siemens:** Siestart hybrid gas turbine and battery — Hall 8b / D40
- 16 **Fluence:** SunFlex Energy Storage technology platform — Hall 8b / D40
- 17 **Home Power Solutions:** Picea is a combination of battery and power-to-gas energy storage, heating support, and indoor ventilation for residential — Hall 8b / D08
- 18 **Fenecon:** Voltage balancing solution for storage systems — Hall 8b / G02
- 19 **Solarwatt:** MyReserve Matrix for commercial application — Hall 8b / G23
- 20 **Robert Bosch:** Combining a power plant with a battery — Hall 8b / E39
- 21 **Autarsys:** State of the art energy storage system for refugee camp in Northern Iraq — Hall 8b / G05
- 22 **Hoppecke Batterien:** Scalable hybrid energy storage system combines lead and lithium — Hall 8b / E16
- 23 **NES:** Storage system with particularly high charging and discharging power — Hall 8b / G04
- 24 **Nilar:** NiMH batteries also for high voltage — Hall 8b / D27

Not participating in the first round of the pv magazine highlight ranking, but also at Energy Storage Europe

Tesvolt: Battery storage system storing electricity for €0.09/kWh — Hall 8b / E01

Stäubli Electrical Connectors: Modular energy system Power-Blox PBX200 — Hall 8b / A31

Kaco New Energy: Bidirectional battery inverter blueplanet gridsave 50.0 TL3-S — Hall 8b / B03

10

Max Bögl

The water battery


Photo: Max Bögl

Max Bögl has built wind turbines with embedded tanks for a water reservoir. The wind turbines are located on a hill about 80 km from Stuttgart. The lower reservoir is down in the valley.

One reason to build hydro storage co-located with wind is, according to Max Bögl, that spatial demand for the upper reservoirs is only marginally larger than that for wind turbines. Capex for the storage part is €300 to €400/kWh.

The water battery ranked in the top five with three jurors, while two ranked it in the lower half. Those who are convinced value the innovation and potential. "It is a very interesting approach with a highly innovative character," says Tobias Federico. Scalability, however, "might not be so easy." The project must show that it is competitive – even with lithium-ion.

Hall 8b / E31

10

Jena Batteries

Organic redox flow battery

Jena Batteries is developing a redox flow battery that uses organic electrolytes instead of vanadium-containing electrolytes. It is more environmentally friendly, because it is free of heavy metals and hazardous acids, the company says. In addition, there is no fire risk.

One of the big questions facing redox flow technology is how it can be cheap enough to compete with lithium-ion batteries (see p. 23). As far as price is concerned, the company does not yet provide any information. However, unlike vanadium redox flow batteries, the price is independent of commodity markets and depends more on scaling, writes the company.

Also for the stack, which sits between the two tanks of a redox flow battery and in which the energy conversion takes place, one could use cheaper materials, since it does not have to withstand aggressive acids. The first pilot plant with a 10 kW/40 kWh battery will now be installed.

As with the other company with which Jena Batteries shares 10th place, the jurors' assessments differ greatly. For two jurors, the company is among the top five submissions. It is especially strong in the categories innovation and USP. "This is a truly novel innovation, which given the expected resource constraints for the existing battery supply chain could help alleviate the long-term challenges to deploy energy storage as part of a transforming energy system," opines Julian Jansen.

Hall 8b / E03

A new concept gains traction

Flexible sector coupling: To date, the energy transition has unfolded primarily in the electricity sector. This limitation should be overcome by sector coupling, which is basically electrification of the mobility and heat sectors. But this alone does not offer a complete solution. Sector coupling must be flexible. To this end, a Berlin-based startup is developing a colossal steel storage tank, and battery storage facilities are being built in Canada along a highway.


Photo: Lumenion

View of the Berlin office of Lumenion, located in an old industrial building.

It is early morning, and already the smell of heated steel wafts through the room. Heating surfaces made of stainless steel are connected to heavy cables. In the future, ever-increasing amounts of electricity produced by photovoltaic and wind power plants will make these heating fins glow. They are at the heart of Lumenion's storage concept. The Berlin-based startup is transforming sector coupling into "flexible" sector coupling.

This term is becoming a new buzzword, as a glance at the conference agenda of Energy Storage Europe in Düsseldorf reveals. In three sessions, experts at the conference will spell out in minute detail what this means for the individual sectors.

Flexible sector coupling aims not only to overcome a particular technical difficulty, but also to tackle an economic one. Think of cogeneration plants, which are generally heat-controlled. This means that they do not start feeding power to the grid until they receive a signal from the heating sector that more energy is needed. From the electricity sector's perspective, that's not very flexible.

It is also a matter of design whether or not a combined heat and power (CHP) plant can be run more in line with the needs of the electricity market. Such plants are often designed to run for many hours of operation, usually 4,000 to 6,000 hours per year to produce sufficient heat. If they are to be switched off for longer periods, they have to be designed larger so that they generate the same amount of heat during shorter operating periods.

A steel colossus rises in Berlin

On a street called Bottroper Weg in the Wedding district of the German capital, it will soon be possible to see how the Lumenion concept makes sector coupling more flexible. The startup plans to build the first demonstration of its high temperature steel storage tank before the end of this year, in a residential area with around 1,000 apartments. It will be charged with 720 kW of electrical power and store 5 MWh of energy. It will be connected to a large district heating network and can discharge 100 kilowatts of heat. If required, it can also deliver electrical energy discharged through a turbine.

Some 15 kilometers away, Lumenion has been working for the past year to bring the steel storage tank from concept to reality. The heating fins, which give the laboratory its characteristic smell, are designed to heat the structural steel. The art is getting the energy into the steel in a short time without the fins getting too hot.

A heat storage tank that also produces electricity

When used as CHP storage, some 75% of the stored energy flows into the heating sector, either as process heat between 300 and 500°C for industrial and commercial use, or as district heat and low temperature process heat between 80 and 120°C. Thanks to the storage tank's high temperature, up to 30% of the stored energy can be reconverted to electricity through a steam turbine if power is needed to stabilize the grid, which generates another revenue stream.

To see the advantage of the development, one has to consider the alternative. Flexibility can also be achieved with battery storage prior to the conversion of electricity into heat. But in such applications battery storage cannot be operated economically, as costs are currently more than €200/kWh. In the medium term, battery-based systems will still be well in excess of €100/kWh. They have to go through several useful cycles per day to finance themselves.

The big advantage of the steel colossus is that Lumenion aims to achieve storage costs of €25/kWh, about one tenth of the cost of storing electricity in a battery. The company says that the low costs enable a lower number of cycles and a relatively long storage period of two days. Assuming 20 years of operation and 180 cycles per year, the stored kilowatt hour at the target price would cost less than €0.01. Reconverted to power at 30% efficiency, the energy storage cost would be €0.023, and over 40 years it would be equivalent to €0.015, accounting for the stored heat.

"However, the storage tank is not designed for seasonal applications," says Lumenion cofounder and technical director Andrew Zwinkels, "but for a maximum discharge time of 48 hours. This is compared with a charging time of 10 hours. It is precisely this asymmetry of the storage tank – it decouples a high charging capacity from a lower discharging capacity – that makes the system innovative. This lets us absorb big surges in wind and solar without expensive power electronics; we only need those to deliver the power."

Zwinkels envisages a wide range of applications for the tank-connected combined heat and power plant: for organic farmers, in industrial parks, in commercial areas, or as a district storage facility. There are already plans for what comes after the demonstration in Berlin. "In northern Germany, where wind power sometimes produces huge surpluses, talks on another project have already come a long way," says Philip Hiersemenzel, who was reluctant to elaborate. Hiersemenzel is Lumenion's spokesperson, and the connection is no accident.

He is also press spokesperson for Younicos, one of many renewable energy companies founded by Alexander Voigt. Voigt also happens to be the Founder and CEO of Lumenion. "The nice thing about our system is that the necessary value chain does not have to be built up; it is already on the market – unlike photovoltaics and lithium-ion batteries, for instance," says Hiersemenzel.

Considering the grid and storage function

The project idea has fallen on fertile ground. Current discussions on grid stability and negative electricity prices indicate that the electricity system is already running up against its limits. "The problems of distributed storage often drop out of the system analysis, or the issues of network and storage are mixed," says Andreas Hauer, head of energy storage at the Centre for Applied Energy Research (ZAE) in Bavaria, and Chair of Energy Storage Europe. Storage shifts power over time, networks shift power locally. These functionalities sector coupling alone cannot take over.

> *"From the electricity sector's perspective, that's not very flexible"*

With their innovative concepts, companies such as Lumenion are pushing the boundaries between sectors. Their coupling concepts work even better if the transition is directly combined with a storage system, says Hauer. For these applications the energy supply has to be shifted to meet the demand: "In industrial applications in particular, there is a strict demand at certain times."

Hauer says that the economic value of electricity increases for power-to-gas or power-to-liquid applications in the mobility sector. In electric cars, the form of energy remains the same despite the change in sector. The planned expansion of the charging infrastructure along the Trans-Canada Highway illustrates how additional storage at the sector boundary is also sensible for e-mobility.

Flexible e-mobility

In the middle of last year, eCamion of Toronto partnered with two Swiss companies, Leclanché and SGEM, and the Canadian government to launch a project for the construction of 34 quick charging stations along the approximately 3,000 kilometers of the country's Trans-Canada Highway. Three drivers can charge their electric cars simultaneously at each of the so-called FAST charge stations via level 3 chargers with 480 V charging in about 20 minutes.

To prevent excessive load on the grid, the power comes from large lithium-ion batteries. The standard size of these batteries will be 250 kilowatt hours. "This depends on the projected demand at the respective sites, but the battery capacity is modularly expandable," says Bryan Urban, the North American head of Leclanché. At Energy Storage Europe, battery manufacturer Schmid will be presenting a redox flow storage device coupled to a charging station, which it has also submitted to **pv magazine Energy Storage** Highlights (see p. 7).

According to Urban, the estimated CA$17.3 million (US$14 million) project has now successfully completed its demonstration phase and is currently in transition to the early stage of production as well as site identification and approval. This fall, the first charging stations along the highway will be set up, and by spring 2019 the entire route, with stations about every 100 kilometers, is scheduled for completion. Daniel Seeger

Photo: pv magazine

Andrew Zwinkels, Technical Director and cofounder of Lumenion behind one of his heating fins in the laboratory. He evaluated the long-term stability.

Don’t worry, but keep asking

As both energy storage makers and car manufacturers keep close track of the prices of key raw materials for lithium-ion batteries, the question of their availability is thrust into the limelight. Meanwhile, the recycling industry is gearing up to provide alternative supply chains.

What’s inside? A question seldom heard in modern society hooked on a use-and-discard cycle. Things are taken for granted; wake-up calls go unanswered. But, perturbed by the raw material price spikes, the storage industry recently had many more questions to ask. The immediate answer is: Keep calm, but for a short while it might get rocky.

Last year, the price of cobalt soared by more than 120%. But the arguments of James Frith, Energy Storage Analyst at Bloomberg New Energy Finance, indicate that the overall situation is not that dramatic. First, for the cost of a battery pack this makes only a slight difference. “A 50% rise in the cost of cobalt, from today’s $91,000 per metric ton on the Shanghai market, would only increase the cost of a battery pack by 9%,” explains Frith. And that does not necessarily mean that systems are really becoming more expensive. “This price increase is likely to be absorbed by savings in other areas, so on the whole battery pack prices are likely to continue falling in 2018.” Second, the price increase is not just based on supply bottlenecks. Adding to the shortage, investors scrambled to hoard physical supplies, betting prices would increase further. “The rise in the price of cobalt in 2017 was exacerbated by stockpiling by funds such as Cobalt 27 and Pala Investments,” adds Frith.

So far, there is no indication of a long-term shortage, and no major impact on prices. Nevertheless, the topic of material availability is suddenly here. In the run-up to the Energy Storage Europe show, experts quizzed for this publication highlighted the questions of raw material availability and sustainability of their production and use.

Buried treasure

As one of the critical raw materials for lithium-ion batteries, cobalt has attracted much attention, having ended last year as a hot trading commodity.

There are various cobalt demand scenarios at the moment, which range from about 180,000 to 260,000 metric tons of total demand per annum by 2025. More than 40% of global production is already used as cathode material for the production of lithium-ion batteries. “According to our assumptions, cobalt demand for electric vehicles could reach only 56,000 to 88,000 metric tons by 2025 if the share of EVs increases to 12 – 18% of global vehicle production,” says Siyamend Al Barazi, a geologist at the German Mineral Resources Agency (DERA).

That is why, beyond market ups and downs, geologists see no threat of a severe cobalt shortage in terms of the metal’s availability. According to the U.S. Geological Survey’s (USGS’s) Mineral Commodity Summary issued in January 2017, world reserves were estimated at 7 million metric tons. If one counts cobalt in manganese nodules and crusts on the floor of the Atlantic, Indian, and Pacific Oceans, then according to the USGS estimates, there is an additional 123 million metric tons of resources. However, deep-sea mining for now remains out of the industry’s depth.

The by-product mechanism

Clearly, it is not only the availability, but also the mining economics that count. “The real problem is not the availability of resources, but the cost of extracting them,” Frith underlines.

With the exception of only one deposit in Morocco, cobalt is mined as a by-product of copper and nickel, and therefore is linked to the production of these commodities, and “2016 showed how production cutbacks of nickel and copper miners and refiners in Australia (Yabulu Nickel Refinery), Brazil (Niquelandia Nickel Refinery), and the DRC (Kamoto and Tilwezembe mines of Katanga Mining Ltd.) directly affected cobalt output,” explains Al Barazi. “Steep price increases, such as the one observed in 2017, are the result.” Moreover, he estimates that when copper and nickel producers operate under healthy market conditions, cobalt supply will meet future demand.

Meanwhile, mining companies are announcing increases in cobalt output to cater to the market. Seeking to cement its number one position on the global market, Anglo-Swiss mining giant Glencore announced in December last year plans to double its cobalt output over the next three years, following supply negotiations with Tesla, Apple, and Volkswagen. Also, junior mining companies are eager to get their slice of the cake.

Another raw material that keeps investors on their toes is lithium, which the European Commission does not even characterize as critical. In 2017, the USGS estimated that worldwide lithium reserves were 14 million metric tons, whereas production stood at 35,000 metric tons. “Based on the current known lithium reserves and production, there is enough lithium for the next 440 years,” says Al Barazi, adding that this is not a fixed number and can vary according to annual consumption and further exploration of lithium deposits.

In addition to being more available, lithium is also cheaper to extract. Nonetheless, its price has not remained immune to the burgeoning demand. It saw its peak in 2016, when spot lithium carbonate prices in China increased up to 300%, based on an acute, but temporary shortage from Australia, while the rest of the world experienced spot price increases of approximately 40% to 60% on a yearly basis. Overall, prices for lithium have jumped over 200% over the last five years, as miners struggled to answer to an uplift in demand. As a result, all industry players are looking to broaden their market reach by expanding their mining operations. "In the next couple of years, we expect a glut of lithium to come online, as miners such as Albemarle and SQM look to significantly increase their lithium production," Frith says. After ending a long-running dispute with the government, SQM announced plans to step up its production by an extra 349,553 metric tons until 2030. Others, meanwhile, explore new deposits, like in the case of the world's largest iron ore producer Rio Tinto, which is looking to start lithium production in Serbia in 2023.

But to what degree could the raw material price rally reflect on energy storage prices? "It takes about six months for the price of raw materials to reach battery manufacturers, so the rise in cobalt prices in 2017 will now be hitting their profit margins. In fact, we have already heard of some manufacturers passing these costs on to their customers," says Frith. Nonetheless, he says that overall in 2018 the prices will keep falling, although at a slower rate than the decrease seen in 2017, when the volume weighted average battery pack price across the industry fell 24% to $209/kWh. The downward price curve will be a result of savings in other areas and due to the Chinese market, which already has some of the lowest prices, at an average of $191/kWh.

Also in the long run there is no need to worry. "Our calculated learning rate of 18% means that every time the volume of batteries produced doubles, prices will drop by 18%. These price declines will be driven by economies of scale as 'gigafactories' continue to grow to an optimal size of ~30 GWh/year, increases in the energy density of cathode materials, adopting for example NMC (811) which contains eight parts nickel for every one part of manganese and cobalt, and eventually a step change in technology, which may come in the form of solid-state batteries or high voltage lithium-ion batteries," adds Frith.

Photo: Umicore

Belgian firm Umicore has a maximum annual recycling capacity for around 7,000 metric tons of lithium-ion batteries.

Recycling: heading to profitability

Another major sustainability topic is recycling. For battery manufacturers, a circular economy would not only ensure a responsible disposal of hazardous waste, but could also reduce their dependence on

Umicore's metal recycling plant in Hoboken, Belgium.

traditional raw material supply chains. In the case of Europe, recycling is far more than a desired scenario, it is legally compulsory and regulated at both the EU and national levels. In accordance with the Battery Directive 2006/66/EC, battery landfill is forbidden, and the mandatory recycling is part of the Extended Producer Responsibility, meaning that if the recycling operation is not economically profitable, it has to be funded by the battery producer.

In this regard, the focal questions are recovery rates of different materials and economic viability of the recycling processes.

The Battery Directive reads that a minimum of 50% of batteries by average weight must be recycled, setting no mandatory amounts for particular materials. But, in the case of certain metals, such as lithium, mining is still cheaper than recycling. "The mandatory percentage target is respected for lithium-ion batteries," says Claude Chanson, General Manager of Recharge, an association representing the battery industry in Europe. So, the average recovery rate comes from other metals. "State of the art recycling facilities gain around 50%," says Reiner Weyhe, Managing Director of German recycling firm Accurec, adding that this includes over 90% of cobalt and more than 95% of copper and iron. But also 0% of lithium. Today closed-loop recycling is not "commercially viable" he notes. What is more, at the moment recovered materials are not specifically intended to be reused for battery manufacturing. "However, possible market tensions in case of strong demand for battery active material precursors could help the development of this closed loop," adds Chanson of Recharge.

Last June, investment bank Morgan Stanley said it forecast no recycling of lithium at all over the decade ahead, but efforts are being made to improve the practice. "Last year, Umicore has introduced a new recycling process for lithium, which ensures a recovery rate of at least 70 – 80%," says Matthias Buchert, Head of Division, Resources and Transport at German non-profit Öko-Institut.

Belgium's Umicore is both a battery component maker and a recycling firm. The company is touted to know the formula for closed loop recycling. Specifically, it applies a pyrometallurgical process on waste batteries through which it gets an alloy, as an intermediate product, containing cobalt, nickel, and copper. In the subsequent hydrometallurgical process, the alloy is further refined so that the metals can be converted into active cathode materials for the production of new rechargeable batteries, thus closing the circle.

More efficient recycling seems therefore within reach. "In the case of Europe's recycling firms we can speak only of small-scale recycling by now," says Buchert. Umicore has a maximum recycling capacity on a yearly basis of around 7,000 metric tons, and Accurec has around 5,000 metric tons. Their capacities are, however, expected to grow substantially over the coming years as more batteries reach end of life," he says, adding that in a few years they could reach 60,000 metric tons. "Then we will be speaking about the economy of scale, which as a rule comes with greater efficiency and lower cost."

Also Chanson of Recharge agrees the capacities will enlarge when the need arises. "But a big question which is raised is the risk of having the waste batteries exported outside of Europe, looking for better profit owing to less controlled recycling conditions and targets," he says. This would put the circular economy in the EU at risk and undermine the European recycling business. "Unfortunately, it is much more difficult for the EU regulation to address this issue, also linked to external trade conditions," he says.

Nevertheless, London-based commodity recycling company CRU forecasts 11,600 metric tons of cobalt to come from recycling in 2021, up from 7,110 a year in 2017, and 24,900 metric tons by 2026, accounting for 9.7% and 17.9% of the total market supply respectively. It is at least a start.

Marija Djordjevic

Aerial view of lithium mining operations close to the town of Silver Peak in the Nevada desert, USA.

Flow battery breakthrough?

Lithium alternatives: Redox flow technologies have grown quite mature, but despite some big letters of intent, the industry is still waiting for the technology's major breakthrough. Experts who will present at Energy Storage Europe address the big questions the technology must answer as it flows into the mainstream of energy storage.

The redox flow laboratory at the Karlsruhe Fraunhofer ICT, where the large electrolyte tanks can test storage systems up to several hundred kilowatts.

It's pitch-black, although the walls are made of bright white salt, and there are no sounds and no smells. "The caverns here have a height of up to 400 meters and a diameter of up to 80 meters," says Ralf Riekenberg, project manager at EWE Gasspeicher. The German energy company's area of operations extends to the North Sea coast, where there are many of these underground caves, some of which are currently used to store natural gas. "The cave is deep enough to fit the Eiffel Tower in," says Riekenberg.

The company made headlines last year with plans to build one of the world's largest redox flow batteries in two of these caverns, with 700 MWh of capacity and 120 MW of power. It's the same opportunity that the storage market experts in **pv magazine's** roundtable (p. 27) identified for redox flow batteries to gain a foothold in the lithium-ion dominated market. After that, manufacturers will have to find niches "where they have a clear place in the market," according to Julian Jansen, Senior Market Analyst, Solar & Energy Storage at IHS Markit. It is not enough to only be competitive when the storage must last longer than in typical applications. Even local geography, such as the availability of salt caverns in this case, can be an advantage for a particular technology.

In its current form, the cave battery is more a declaration of intent to develop the technology than a project to be quickly implemented for the grid. The goal is that it will be realized in 2023. One reason is that the project's business model cannot be finalized, in light of shifting developments in the electricity market, and the unpredictability of regulation.

There are, however, conditions present that suggest such a storage solution could be useful. The coastal region has a particularly large amount of wind power, and local storage could take pressure off the grid. "Surplus power that already exists could be stored there," says Riekenberg. At present, the wind turbines are stopped when the electricity is not needed or cannot be removed because the grids are not designed for peak performance."

A similar redox flow project is underway in Dalian, China. There, Rongke Power plans to develop an 800 MWh storage facility, and wants to use it by 2020 to peak shave 8% of the region's load. The Chinese company is using vanadium redox flow technology, developed by UET, based in Washington State, USA. This is the most common redox flow technology, and offers some benefits for developer Rongke Power, as the company also uses vanadium in its steel business. "Companies in the steel sector can use vanadium redox flow batteries as a parallel revenue source when demand for steel drops," says Lorenzo Grande, a technology analyst at IDTechEx who has published a study on the redox flow market.

For the salt caverns, on the other hand, EWE is relying on a new redox flow technology that is more environmentally friendly and works in a salt solution. It

Currently utilized as a gas storage facility, these salt caverns in Northern Germany will be used to create an enormous redox flow storage facility.

uses organic polymers and was developed at the University of Jena. In the initial phase of the project, EWE will also build test installations, most likely at the Fraunhofer Institute for Chemical Technology in Germany, which is equipped with tanks for huge amounts of electrolytes for redox flow technologies. This is where Peter Fischer, who answers some of the most relevant questions on the state of redox flow technology in the following interview, carries out his research.

pv magazine: ***One could get the impression that energy storage devices are primarily lithium-ion batteries. Although redox flow batteries have been around for a long time, they appear to have fallen behind. What is the status of the technology?***

Peter Fischer: The expression "fallen behind" is quite misleading in my opinion. For many years, stationary storage has been dominated by lead-acid batteries. At the moment, lithium-ion battery systems are emerging and have taken over in terms of the number of installations and installed capacity during the last years. The lower number of redox flow battery installations is due to the lack of business cases for capacity storage. The idea of redox flow technology is to provide large storage capacities at a potentially lower price. But the business model for capacity storage is expected to change very soon, particularly in Germany, as federal funding within the EEG will fade out.

Mostly unnoticed by the general public, flow battery prices have also halved over the last five years. The price erosion has not been as dramatic as for lithium-ion batteries. But nevertheless, flow battery technology has become more competitive, and manufacturers are no longer afraid to provide the same guarantees as lithium-ion storage manufacturers provide today – these statements count of course only for the major players.

For which business models and in which regions do you see the main applications in the next three years?

The most promising applications are multi-megawatt installations in the transmission grid, which could serve for peak shaving for utility grid services or small to medium-sized factories. At the moment peak shaving is not profitable, since electricity prices are too low for the mere storage of electricity to provide a business case. But with the combination of other business cases like frequency regulation, such energy storage can become profitable in the near future. Costs of grid service will increase over the years, and with the low capex prices of renewable energy, capex deferral scenarios are also more likely to pay off. Widely discussed at the moment is the stacking of business models for flow batteries, to make the business model for capacity storage more attractive to investors.

One difficulty is to accurately estimate the lifetime of redox flow batteries and to characterize it via the cycle life. Why is it more difficult to specify compared to lithium-ion batteries?

During battery operation the reaction is accompanied by chemical changes on the electrode surface. Electrical energy is stored in the form of chemical energy on the electrode surface. As the conversion rate of a chemical reaction is seldom 100%, a small quantity of the material cannot be recovered during a reversible reaction cycle, meaning a back and forth reaction on the electrode that corresponds to charging and discharging the battery. These losses can be counted in charging and discharging cycles and projected on the lifetime of a battery.

In a flow battery, the electrical energy is stored in a liquid, and not on electrode surfaces. As the electrochemical reaction takes place in the liquid, the two electrodes don't change during the charging and discharging reaction. Electrochemists name these types of electrodes inert electrodes. In ideal conditions, these types of battery electrodes will not degrade or wear out at all. In reality, this is of course not really true, as the electrodes can face corrosion or wear. Also, the electrolyte capacity can fade, though in most cases it can be recovered quite easily. But this is why lifetime of flow batteries cannot be projected directly through testing cycles of charge-discharge operations.

What do you advise EPCs and investors on how they should estimate the lifetime of redox flow batteries?

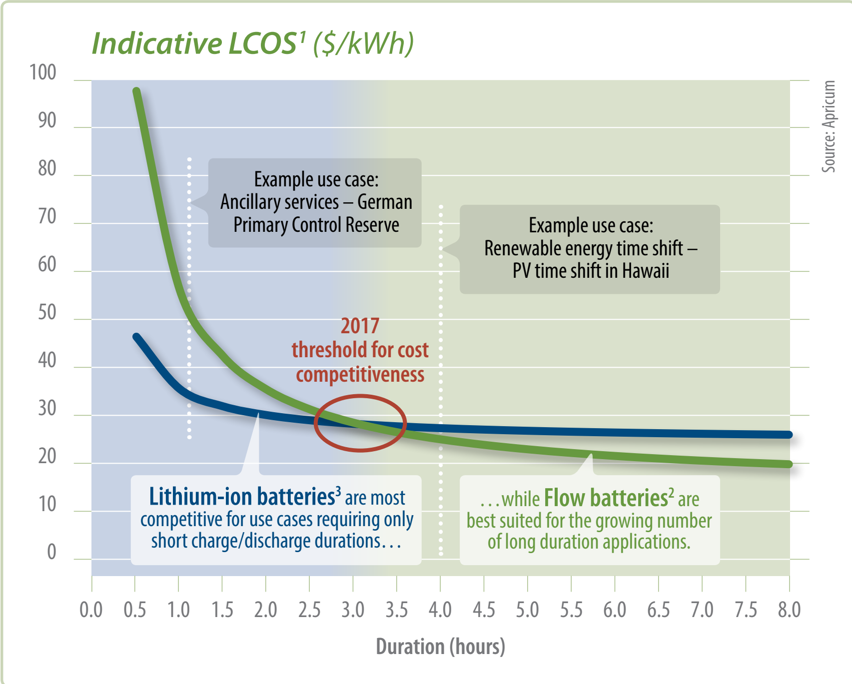
The lifetime of all battery systems depends on their charge and discharge history, temperature history, etc. This also counts for flow batteries. The data from cycle tests are more interesting if you want to compare battery chemistry in different conditions than predicting the lifetime of real systems. I can fully understand that EPCs wish to have indicators for the depreciation of their investment.

The flow battery is in any case more related to a fuel cell. Lifetime estimation is also difficult in fuel cells, as fuel cell electrodes also work with inert electrodes. The lifetime of a fuel cell is usually compared by soft numbers like operating hours, to provide guarantees for a customer.

In flow batteries it would be even more difficult to provide such data, as charging as well as discharging operations influence the lifetime. I think in the future battery manufacturers will provide guarantees, which will of course vary based on how confident the manufacturer is with their product. The guarantee will be structured like a service contract. As

Capacity with potential

Graphic: Harald Schütt/pv magazine



Redox flow storage: Considering all relevant aspects, flow batteries can show lower lifetime cost than lithium-ion for shorter durations than you might expect.

The consultancy Apricum has compared levelized cost of stored energy (LCOS) for lithium-ion and redox flow batteries. The indicative LCOS depends on the charge/discharge durations of the batteries: i.e., the ratio of capacity to power. For example, one hour of storage duration needs a battery with a capacity in kWh equal to its power in kW. For three hours duration, the capacity is three times the power (a C-rate of 1/3). The figure illustrates that, based on capex figures Apricum sees in the market today, flow batteries can have an economic advantage over lithium-ion batteries already for durations between three and four hours. Increasingly, applications for energy storage demand longer charge/discharge durations. This may provide significant opportunities for redox flow batteries. However, system costs of individual flow, as well as lithium-ion batteries, vary substantially, and many specific project and technology parameters have an impact on the economics via LCOS, such as battery and project lifetime, degradation, efficiency, and charging power price. In particular, flow batteries can play to their strengths when a lifetime of 20 years or more is valued.
However, it should be noted that a low LCOS is not the sole selection criterion – other aspects such as bankability could play an important role. See also the **pv magazine** roundtable debate on page 27 for further discussion of these results.

Assumptions for the LCOS calculation: 1) 350 full cycles per year, $0.05/kWh charging power price, 9% discount rate, $205/kW capex for AC power electronics, annual O&M cost of 2% of system capex, no residual value;
2) DC system capex for the redox flow battery is the sum of $190/kWh (usable energy) and $890/kW (power), 20 year lifetime, 70% AC RT efficiency, 0.4% annual degradation;
3) DC system capex of $330/kWh (usable energy), 10 year lifetime, 80% AC RT efficiency, 1.6% annual degradation.

soon as more installations are out, statistical data can provide more security on how the lifetime of a flow battery system can be projected.

Why does the industry need to look for alternatives which are cheaper than vanadium?
The limiting costs for electrolytes of $60 to $80/kWh are still quite high, if you compare to the projected costs of lithium ion cells, which are at around $150/kWh. The investment cost of a redox flow battery is still significantly higher than that of a lithium-ion battery. They are also the reason why lifetime considerations are crucial. When the lifetime of redox flow is longer or refurbishing costs are lower, they can be advantageous. A lot of research is done to provide cheaper redox flow energy storage materials, to provide competitive systems for capacity storage.

What are the most promising alternatives to vanadium? What storage costs can you get with them, and what is the state of development?
Different systems are being discussed. For high power storage applications, hydrogen bromine flow batteries provide an interesting alternative, since hydrobromic acid is a very cheap storage medium with a potentially high capacity. This system is a kind of a hybrid system of a fuel cell with a flow battery. Nevertheless, these systems are quite complex today, due to reversible hydrogen storage and choice of stable materials. Organic redox coupling is also widely discussed, as it can potentially be cheaper. Chemical stability for multiple charge and discharge operations of such redox systems is often not sufficient. At the moment different research activities are concentrated, to improve stability as well as energy density of such electrolytes. Zinc systems like alkaline zinc iron, neutral zinc bromine, as well as more futuristic systems like zinc slurry air are also being discussed. These are hybrids of a zinc battery with a flow battery. The first two systems are already commercially available products.

Text & interview by Michael Fuhs

Driving long-term growth

IHS Markit Senior Market Analyst, Solar & Energy Storage, Julian Jansen notes that 40% of the total energy storage pipeline aims at solar plus storage projects. He explains how this combination is developing into a surprisingly good working business model for storage. It can radically change the energy supply landscape for good.

The 10 MW Clayhill solar farm in the U.K. features a co-located 6 MW storage facility. The U.K. plans to provide further guidance on the FIT and Renewable Obligation (RO) schemes for co-located sites.

With almost 200 GW of utility-scale solar PV deployed since 2010, representing around 50% of total solar installations in that time, its importance as one of the pivotal generation technologies of the future can no longer be contested. Based on this impressive growth, the biggest barrier to achieving a fully renewable energy system remains the inherent intermittency of solar and other renewables.

Energy storage in its many forms has the ability to make solar and other renewable generation fully dispatchable, as well as potentially solving many of the barriers ranging from solving network infrastructure constraints to enabling off-grid energy systems. Despite this, to date only around 420 MW of battery storage coupled with utility-scale solar has been installed – with the number skewed by a handful of large-scale projects in Asia. This contributed to the prohibitive costs of energy storage in the past.

The opportunities for deploying utility-scale solar plus storage are multi-faceted and diverse, varying not only by country but from site-to-site. Of course, energy storage located as a standalone asset along the distribution or transmission may also alleviate challenges caused by the growth of renewables. However, there are universal benefits of siting storage alongside solar as the share of intermittent renewables, both overall and on local networks, increases. In short, the more solar power is generated and fed into the grid, the greater the value of storing power.

The graph (p. 26) highlights how, going forward, more than 40% of the total energy storage pipeline aims at solar plus storage projects. This illustrates a clear shift away from most past projects that served single use cases such as frequency regulation or capacity requirements. What can be observed is that the solar plus storage pipeline aims to provide some of these values as part of their proposition, but can also serve a range of additional use cases or, as often seen, simply take advantage of existing network infrastructure at the solar site.

Building a successful business model

New value is now emerging for storage on the utility side of the meter, primarily from capacity requirements and the integration of utility-scale solar and island microgrids. This leads to greater growth in the longer duration energy storage segment, especially systems of two to four hours (and above) in duration. In theory, energy storage can provide multiple use cases when paired with utility-scale solar:

1. Time shifting generation: While time shifting can capture a range of applications, for this specific analysis we define it as storing solar power and discharging it at a later time, typically under a PPA type agreement with a utility offtaker. Making solar generation dispatchable by having storage on-site makes it comparable with a traditional generation resource. This will be crucial in facilitating continued growth and integration of solar power. Such a model will become especially attractive in locations with high electricity prices, where solar plus storage can deliver lower cost electricity, or where there are significant differences between peak and off-peak wholesale electricity prices, and thus a power producer can maximize revenue. Additionally, the offtaker may be prepared to pay premium PPA prices (in comparison to a PV plant without storage) when procuring solar plus storage in return for added flexibility. Should this be the case, investors will have a clear benefit from co-locating storage, as long as they take into account the utility requirements and size the project accordingly. Currently what can be observed are energy storage system durations between two and four hours, while the feasible power ratios vary widely, but are commonly between one-to-one and two-to-one (PV to energy storage).

To provide an example, let's look at Tesla's solar plus storage project for Kauai Island Utility Cooperative in Hawaii. The 52 MWh of energy storage is necessary, as during the day the island's grid is unable to absorb additional solar generation, while during evening peak time the electricity supply relies on expensive diesel. By co-locating the storage system with the solar plant, electricity can be stored during the day and discharged in the evening. The island utility does not have to curtail peak solar generation and also is able to procure electricity at around 10% less per kWh in comparison to existing diesel generation.

2. Ramping: Energy storage can be added to a utility-scale PV system to perform 'ramp rate control.' Here, a storage system would be added to overcome a specific technical challenge by ensuring that a system's output does not increase or decrease too quickly. An example would be passing cloud cover rapidly decreasing output from the solar system and potentially destabilizing the grid. Such systems have been made relatively common in Puerto Rico where minimum technical requirements for interconnecting renewable generators require the addition of energy storage systems specifically to manage the 'ramp rate' of power.

3. Distribution network support: In many regions where intermittent generators (renewables) contribute a very high proportion of power generated, grids can become unstable, either leading to reliability issues or to limits being placed on grid connections for renewables. If a storage system is sited alongside a utility-scale solar system, it may reduce the need for network connection upgrades by providing an effective way of curtailing peak output.

The ability of energy storage to alleviate constraints on the distribution grid is currently shown by Western Power Distribution's 'Solar Storage' trial in the U.K., using a 640 kWh battery storage unit. Following some teething problems, this particular pilot has shown that the storage asset can technically provide a range of services to a distribution network operator when co-located with solar. However, the trial also highlighted that currently there is no real business case that offers remuneration to a developer. A business case may become apparent, if in future storage becomes a mandated addition to utility-scale solar plants in constrained territories.

$36/MWh in sight?

Highlighting this diverse set of applications shows that energy storage is a crucial tool to enable the long-term growth of utility-scale solar. At the same time, the business case is highly uncertain today and only exists where premium remuneration is available for adding flexibility, a mandate for adding energy storage to utility-scale solar exists, or regulation allows for effective value stacking with external revenue streams. The key factors for investors to consider when assessing individual project feasibility are:

- High power prices and generation costs
- Weak or constrained grid infrastructure restricting deployment of utility-scale solar;
- Strong renewable targets and respective growth in renewable deployment
- Strong conditions for solar generation
- Significant variation in electricity prices throughout the day;
- Regulatory frameworks allowing the provision of ancillary services and capacity with solar plus storage systems.

AT A GLANCE

- It has been a much talked about topic for years, now we are finally witnessing how utility-scale solar plus storage plants can radically change the energy supply.
- 420 MW of battery storage coupled with utility-scale solar has been installed globally.
- Now 40% of the total energy storage pipeline aims at solar plus storage projects.
- The United States is driving early deployment of utility-scale solar plus storage across a number of utility tenders that may reward the addition of storage to solar projects.
- Australia has made the headlines based on an eye-watering pipeline of 2.1 GW for storage projects paired with utility-scale solar.
- In Europe, the United Kingdom and France are driving the deployment.

On an LCOE basis, stand-alone solar will always be cheaper than solar plus storage. However, the added benefits – whether it be delivering power in the evening peak period or providing additional ancillary services to network operators – may make solar plus storage by far more valuable, particularly as the cost of storage continues to fall. IHS Markit currently forecasts a 17% drop in utility-scale solar PV system prices by 2021 and a 31% drop in energy storage system costs by 2021, in comparison to 2017.

Future price declines and favorable market conditions were recently illustrated by solicitation results from Public Service Company of Colorado (a subsidiary of Xcel Energy) in the United States. Here solar plus storage PPA price proposals came in at a median price of $36/MWh, significantly lower than all previous prices for utility-scale solar plus storage projects. Given that these results are preliminary and only form part of the utility's future resource planning, one cannot infer any detailed information on individual projects. If any of the bids are to be realized, they would not have to be commissioned before 2023, so one cannot equate this number with what is achievable in the market today. What the results do offer is a glimpse into the future where solar plus storage is becoming an economic and flexible source of clean energy.

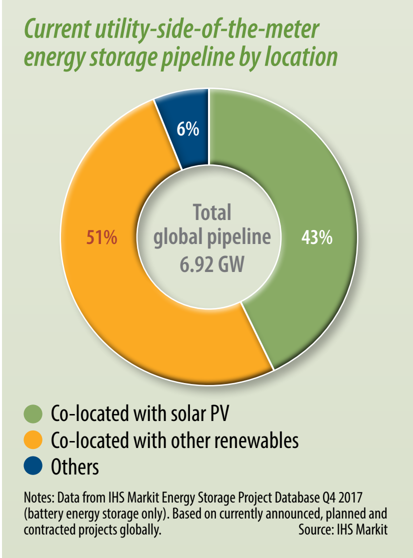
"New value is now emerging for storage on the utility side of the meter"

Where will we see the greatest opportunities?

In total, IHS Markit expects between 20 and 26 GWh of energy storage co-located with utility-scale solar to be deployed from 2018 through 2025 across a wide range of regions. Clear growth opportunities stand out in a number of major solar and storage markets including:

The **United States** is driving early deployment of utility-scale solar plus storage across a number of utility tenders that may reward the addition of storage to solar projects across states such as Hawaii, California, Arizona, and Colorado. Subject to some of the prevalent uncertainty around the solar PV market in the U.S., the country will be leading the short-term development of solar plus storage projects.

Graphic: Harald Schütt/pv magazine



Australia has made the headlines based on an eye watering pipeline of 2.1 GW for storage projects paired with utility-scale solar. It has to be recognized that a large proportion of this project pipeline can be considered somewhat speculative. There are, however, heightening concerns over the stability of Australia's grid, due to the growing penetration of renewables, the wide distribution of its population, and the large number of remote communities. This is working in favor of energy storage, which in combination with utility-scale solar is seen as one of the core future energy resources in the country. Nonetheless, direct remuneration for such projects remains highly uncertain, with the most likely revenue streams coming from capacity/network stabilization tenders, frequency regulation services, and arbitrage.

In **Japan**, as utility-scale solar will account for an increasing share of generation, curtailment is becoming a reality, leading to electric utilities starting to pilot energy storage projects paired with solar generation to improve grid stability through multiple use cases.

At the same time, **South Korea** will further cement its position as one of the leading energy storage markets. Specifically, the Ministry of Trade, Industry and Energy has outlined the country's new energy road map. The target is to increase the proportion of renewable energy in the country's energy mix from 7% to 20% by 2030. As part of the plan, the government will look to increase investment in backup facilities and energy storage systems to overcome challenges of intermittency.

Opportunities for utility-scale solar plus storage are not only emerging in markets that have such strong visibility. In **Europe**, the United Kingdom government and regulator are planning to provide further guidance on the FIT and Renewable Obligation (RO) schemes for co-located sites. At the same time, France has been driving deployment of utility-scale solar plus storage through tenders across its non-interconnected zones (islands and overseas territories).

In island locations across the world, solar plus storage is becoming an economically attractive option to displace diesel generation, while in markets across **Latin America**, a strong short-term growth in utility-scale solar is creating grid constraints that can be alleviated through energy storage. For example, in Baja California Sur (Mexico) added flexibility through energy storage is becoming a requirement for the connection of new renewable plants.

As this specific market segment is being established, such challenges will be overcome, and the willingness of policymakers, regulators, and utilities to take advantage of this low-carbon and reliable source of electricity offers a positive outlook. IHS Markit expects that solar plus storage will become a cost competitive source of electricity across most major utility-scale solar markets from 2020 onwards. In the meantime, early opportunities are emerging across the globe from the U.S., through Europe and the Middle East, to the major markets of Asia and Australia.

Julian Jansen

Masked surprises

Energy storage is a highly dynamic market. Nevertheless, it is not always easy to pick out the most interesting news from developments that have not been widely reported. In the pv magazine roundtable discussion, we found three of the major themes: They are dealing with business models beyond frequency regulation.

Michael Fuhs (pv magazine): I have the impression that in the storage community the discussions are repeating themselves. On the one hand, there is news of fast growing markets, and on the other, companies frustrated by regulation. We also heard this message last year at Energy Storage in Düsseldorf. Have there been developments since then that have surprised you particularly?

Ravi Manghani (GTM Research): One of the most surprising things that I came across in the last few months is very recently Xcel energy in Colorado released their requests for proposal that are currently ongoing, all-source solicitation. The surprising element was that they had 100-plus bids for either standalone or renewable paired storage. We don't know details of each one of those bids, but what was explicitly reported in their document is that all of those 100-plus bids were with lithium-ion batteries, except for the one separate category for compressed air energy storage. And what makes it all the more surprising in terms of industries, technologies and landscape perspective, is that there were a few bids in there that were six, eight and ten hour storage bids.

Fuhs: Which could, according to common sense, favor redox flow chemistries ,for example.

Manghani: As we start to move to longer duration storage there is scope for other technologies, like flow batteries or some other chemistries, or electro-mechanical based technologies. And yet we did not see a single bid for these. All these projects have a completion date of 2023. If we read between the lines, the developers who bid into these projects don't expect by 2023 that we will have competitive flow battery technologies that they can trust.

Florian Mayr (Apricum): Regarding the general choice of lithium-ion batteries over flow batteries: How long was the PPA or the guaranteed remuneration in the request for proposals? That is also important, as if you have, let's say only a five-year PPA, then flow batteries that have very long lifetime and low degradation cannot fully play out their advantages.

Manghani: The contract duration was left open. But most of the bids are going to be in the 20 or 25-year range, which again speaks to the contrary that flow battery technologies are better suited to last so long.


Photo: Younicos

A 6 MW/10 MWh lithium-ion battery installed by Younicos in the UK. "In the UK regulators are showing a much stronger will to provide market access to energy storage than in most other European countries," says Florian Mayr.

AT A GLANCE

- The combination of large photovoltaic systems with battery storage is a larger field than was thought a few months ago, but only in some regions.
- Redox flow storage did not come into play in tenders for solar installations with storage facilities in the USA, although the conditions might have worked well.
- The differences in the storage market, especially between the U.S. and continental Europe, can partly be explained by the different conditions. In addition, it plays a role whether one understands the energy transition as something bigger than a pure infrastructure change.

Mayr: An explanation could be bankability. There are only a few huge corporations, such as Sumitomo, in the flow battery business, while a lot of lithium-ion batteries are coming from big companies like LG Chem, Samsung SDI and Panasonic. This could lead to higher financing costs for flow batteries.

Matthias Leuthold (RES): Why were you so surprised? I would say it is a common disbelief from three to four years ago when we thought everything beyond four hours is the home turf for redox flow. We cannot find cheaper redox-couples than vanadium – the only reliable redox flow technology we know is vanadium redox flow – I haven't seen any major installations in other technologies. Now, one can buy a low power/high energy lithium-ion battery for capacity prices well below €300/kWh, and for very large projects soon below €200/kWh. In contrast, I see that manufacturers of redox flow batteries proudly present that they can get below €350/kWh storage capacity. I don't understand how they get business. With the small volume redox flow battery suppliers, the cost reduction potential is too small. We also have to be aware that lithium-ion batteries are not only high-power batteries. The low power branch has made significant progress and there are dedicated manufacturers for pure energy cells, which are big enough to have bankability, which is a serious question. We had a project where a customer decided on redox flow and it was only bankability that didn't make it possible.

Mayr: Matthias made an important point. To assess future competitiveness, decreasing costs due to economies of scale and technological improvements have to be taken into account. In this context, the upcoming massive growth of e-mobility will drive down costs of lithium-ion batteries independently from the development of the stationary energy storage segment, something flow batteries cannot benefit from. On the other hand, I'm seeing increasingly low CAPEX for vanadium flow batteries on a DC level. In our close work with storage technology providers around the world, we are getting first hand insights on prices that translate into about $190/kWh for the energy components plus $890/kW for the power components achievable already today. Based on these prices we conducted an LCOS analysis (see page 23) in order to understand how competitive a top-of-its-class vanadium flow battery can be today, compared to lithium-ion and what the resulting duration time threshold is. I am hearing a lot about six, seven and eight hours as a threshold beyond which redox flow is competitive. According to our calculation it is closer to three or four hours. However, please note that the analysis does not include bankability or any residual value, which both impact LCOS as well.

Fuhs: What do the others think about CAPEX assumptions?

Julian Jansen (IHS Markit): I think that is quite an aggressive and optimistic CAPEX assumption. Part of the problem we have really seen for flow batteries comes back to what Matthias said. It is not just about the cost factor and capital; it is about longer-term risk and the bankability, and possibly a lack of faith in the warranties that can be provided. Another issue is that as a customer do I actually have any security that the company that I am buying this technology from will still be around in three years' time? I still believe in the potential of flow batteries. But I think companies really need to do a much better job at finding their niches and segments where they are not competing with lithium-ion batteries, but where they have a clear place in the market. It is not just the storage duration that counts, but also the location, cycling requirements and the types of application being provided. By focusing on their strengths, some flow battery players are doing quite well finding these niches. Those simply competing with lithium-ion on a cost by cost basis will struggle in the foreseeable future.

Jonathan Gifford (pv magazine): I know the Australian company Redflow from South Australia and they are very much looking for telecommunications in Southeast Asia. What are the other use cases that you think play to the natural strength of flow batteries?

Manghani: Flow batteries can last much longer than lithium-ion batteries and typically require less O&M, which again points to applications that are remote in

Michael Fuhs

Michael Fuhs has been editorial director of pv magazine since 2010. As editor in chief of the German edition, which has had a very strong focus on the storage market since 2012, Michael has a slightly European perspective in this panel discussion moderation. He holds a PhD in physics and worked for German newspapers, national public radio and TV before joining pv magazine.

Julian Jansen

Julian Jansen is a Senior Market Analyst at IHS Markit Technology. He focuses on battery storage market activity and industry trends, as well as analyzing key value drivers and emerging business models driving storage deployment.

Additionally, Julian provides high level consultancy and strategic advice for bespoke projects..

Matthias Leuthold

Mathias Leuthold is Head of Storage at RES Deutschland. RES is a major supplier of medium and large-scale storage installations. Before joining RES he led the research team on application of storage systems at RWTH Aachen. Matthias has led the development of numerous projects, including experimental 5 MW storage demonstration facility system M5Bat.

nature, that do not require the level of TLC that deep cycle batteries or lithium-ion batteries may need. So we are talking about applications like microgrids. Much like telecom, in microgrids again there is a different variety of application, arguably some island nations, some island type applications, even in mainland, developed countries or even developing countries. I think there is a huge variety of energy access related applications, that flow batteries could target.

Fuhs: What do you think about the cost assumptions of $190/kWh for redox flow?

Manghani: I stand in the same camp as Julian who thinks these cost estimates seem fairly aggressive. I am not saying that these costs are not achievable. Some of the flow battery vendors that we spoke with are confident that they could get to fairly low prices. The question is whether there is a market big enough for flow battery companies to scale up. If there was a market for vanadium flow or any other kind of flow batteries, we would see investments by flow battery vendors or their financiers into building up giga-factories. But we haven't seen that yet, excluding one or two vendors now looking to build facilities in China.

Fuhs: How concrete is this huge 800 MWh redox flow project in Dalian, China?

Jansen: It is a little bit of a mystery. The latest I heard was that it is going ahead, but as with many projects in China it may be built in several phases. Then the case will be reevaluated, and the next phase goes ahead. So I think it is unlikely that 800 MWh will be commissioned in one go. But I do think China is serious about all types of battery technology and it will be quite interesting to see what impact they have on the global market. If they want to make it happen, they make it happen; they do not sit around on regulations for years.

Fuhs: Regulations and market growth is related to business models. Has anybody been surprised by recent developments?

Jansen: If you would have asked me a year ago, I would not have expected the size of the pipeline in Australia, neither for utility-scale solar nor for utility-scale solar plus storage, for which the pipeline has reached more than 27 GW and 2 GW respectively. These expansion plans have taken me and lot of people by surprise. Another interesting trend can be observed in smaller markets. They are not as big an opportunity as any of the major markets, but I think the developments in the Czech Republic, Austria and Sweden are worth watching.

Fuhs: As far as I heard, the inspiration to build the 100 MW big Hornsdale storage plant was a blackout. Is this really the business case, and how is this service rewarded?

Manghani: The Hornsdale project was developed with some funding provided by the South Australia government that basically looks to be a resiliency contract, which of course does not cover the entire cost of the project. So the plant has the ability to participate in the Australian national electricity market.

Fuhs: Business model beyond frequency regulation is one of the big topics we defined as being of enhanced interest this year. A lot was written about the gas peaker replacement by storage. Peakers are plants that mainly serve peak load in the grid and are, for example, rewarded by capacity markets. However, isn't it often the case that experts are spending lots of time discussing it, but it hasn't happened so far?

Manghani: Peaker replacement opportunity is definitely getting more and more real. Again, some of it is being driven by some progressive-thinking regulators. In early January the California Public Utilities Commission ordered that the utility PG&E should look at storage and other distributed energy sources, rather than renewing a contract for three gas plants, two of which are peakers. Some of the development is being driven by the policy makers. But if we look at pure economics, we come to the conclusion that in certain markets peaker plant replacement as an application starts to get competitive in the next four years, especially in markets with a significant delta between the off-peak and peak wholesale prices, e.g. in the west coast and northeastern markets in the U.S. We assumed that four-hour energy storage is sufficient, knowing that this duration doesn't necessarily replace peakers. Some of the peakers are required to run six or eight hours, and there can be weather events that require peaker plants to run for an entire day. If we assume that the cost reductions continue until 2027, about half of the new peaker plant capacity that's expected to come on line could be addressed [with storage].

Fuhs: What can we learn from this, particularly for Europe?

Jansen: I agree with Ravi's expectations regarding U.S. peaker plants, which are very much in line with our team's modeling. European energy markets are fundamentally structured in a different way. We don't have utilities procuring peaking

Ravi Manghani

Ravi is the Director of Energy Storage at GTM Research, where he focuses on markets and value chain analysis. He has over eight years of experience in storage as an analyst and engineer, and holds a Master of International Business degree from Tufts University, a Master of Science in Chemical Engineering from University of Washington, and a Bachelor of Chemical Engineering from the Institute of Chemical Technology, Mumbai, India.

Florian Mayr

Florian Mayr is partner at the consultancy Apricum and brings a wealth of management consultant experience, combining an enviable knowledge of both the conventional energy and renewable energy sectors. Prior to Apricum, he spent eight years in senior positions at McKinsey & Company and RWE.

In the U.K., regulators are opening up market access to energy storage providers. Pictured: a 6 MW battery at Clayhill solar farm, installed by Anesco.

capacity. The closest we might get is the capacity market mechanism in the U.K., which regulators realized that the structure did not necessarily incentivize the right type of resources, hence the de-rating of energy storage within those tenders. I think capacity as such will not become a primary revenue stream in any European market. It may serve as a secondary revenue stream, at least with the right incentives or market mechanisms. A different perspective could be the combination of thermal generation with battery storage as part of hybrid power plants being able to serve more than one use case. It can be gas turbines, gas engines, or in remote locations diesel gensets.

Leuthold: It is something we also see coming. You have the option of adding thermal storage to batteries, which is making power generation and heat generation more flexible. We see that in several places in Germany now (see page 16). Generally, I am pleasantly surprised that we do see some early movers going in the direction of using storage as peaker replacement or peaker supplement. But one fundamental difference between Europe and the U.S. is that in Europe we have a fantastic grid. The renewable penetration in countries like Germany is largely balanced by the grid and cross border transfer. Therefore, these applications of long duration storage may not happen in Europe.

Fuhs: Another driver, particularly for C&I storage applications in the U.S., is high demand charges. IHS Markit just published a study that the annual installations in this segment will increase from 50 MW in 2017 to more than 400 MW by 2022. The basic driver is also overload in the grid, the same as for peaker plants. So are we not likely to see such a development in Europe?

Leuthold: That is what I think.

Mayr: I agree with you. One reason is that each region is facing different challenges. In many regions in the U.S. the grid is weak, or “all duct tape and bubblegum” as I am told. At the same time, there is more and more renewable energy fed into the grid. On top of this you have resiliency issues that became particularly obvious through the various natural disasters hitting the U.S. in the last few years. So there is an increasing urgency for action to keep the lights on. Well-known initiatives such as the Self Generation Incentive Program (SGIP), as well as high demand charges and time of use pricing reflect the strong intention of both policy makers and utilities to incentivize customers to consume power in a more grid-friendly way, and to contribute to a more resilient infrastructure. Energy storage is obviously part of the solution here and benefiting from these frameworks.

In continental Europe, the grid is typically in a much better condition, and it’s much more densely meshed – we are literally sitting on a copperplate here. That causes high flexibility and reliability of the grid. For instance, in Germany, the mean non-availability of power in 2015 was just about 13 minutes. Hence, the perceived urgency for action to adjust frameworks or create new schemes is in general much lower. Having said this, energy storage can of course add a lot of value in continental Europe if allowed to, for example by providing frequency response or by helping owners of rooftop PV systems to increase self-consumption. But I would not expect that improving market conditions for storage is high on the policy makers’ agenda right now.

Jansen: We see great potential in the U.S., based on a number of core drivers around the economics of peak shaving and demand charge management. One fundamental disagreement I have, is to say that some states in the U.S. have tariff structures that enable C&I storage just because they have a less stable grid than continental Europe. One of the big issues I see in Germany is that it is rapidly falling behind. Implementing the energy transition goes beyond just installing renewable energy and infrastructure. In Germany, politicians completely underestimate future customer powers, both residential and commercial, and do not look to enable distributed energy to become a valuable resource as part of the grid. Especially in Germany, policy makers are putting up road blocks to proper implementation of a distributed, digitalized and consumer-centric

> *“The combination of different types of thermal generation with battery storage will be a very interesting application”*

energy system. Other countries like the U.K., the Netherlands, Switzerland and the Nordics are much more advanced in exploiting the opportunities from flexibility and enabling customers to support the grid.

Fuhs: Would it also make economic sense to change regulations in the wake of what is happening in the U.S.?

Jansen: It doesn't need to be a demand charge. That doesn't necessarily make sense in European countries. What may be more likely are effective time-of-use tariffs that commercial customers can take advantage of. And it also goes back to the 'level playing field' discussion. In most European countries you cannot aggregate distributed generation and small-scale storage without overcoming vast barriers. Look at the U.K.: It faces many challenges, but it is creating a framework that is future-oriented and enables different technologies to provide a range of services in a non-discriminatory nature to the system operator and the distribution network operators.

Mayr: I agree that in the U.K. regulators are showing a much stronger will to provide market access to energy storage than in most other European countries. But building on my argument before, there is also a much higher urgency for action than in continental Europe. Great Britain is an island with far less interconnectors to adjacent countries that could provide flexibility than, let's say, Germany. And there is the phase-out of coal-based generation that comes along with a loss of inertia that eventually triggered the energy-storage friendly EFR scheme, for example.

Fuhs: We see that there are several dimensions, and it could make sense that Germany moves more slowly. But from the U.S. we see almost daily announcements that will push energy storage. Just recently, in one day we learned that Hawaii's legislature is considering income tax credits for energy storage, and that in California energy storage systems connected at customer sites are able to provide services at the distribution or transmission level. This is something we wait for in Europe. Do politicians everywhere just do what makes economic sense, or has it more to do with being conservative or progressive?

Leuthold: Germany is the most conservative and protectionist country. If you look at the design for frequency regulation, only German transmission grid operators have managed to get the German government to request the 30-minute duration for frequency service, which reduces the competitiveness of batteries. Also, if you talk to the German ministry for economic affairs they're quite defensive for any change. I think this is because they got burned by the cost for the energy transition. If we look at this historic aspect and the higher pressure in the U.K., it is clear that other countries are moving more quickly.

Manghani: The important fact is that the energy transition is beyond just centralized infrastructure. We are in a continuum of market development. Customers are more willing to go with decentralized and distributed energy choices. Be it solar panels on the rooftop or electric vehicles. If you look at the regulators' standpoint, they know that the market is going to be more distributed and that customers are going to be more empowered in their choice of energy or mode of transportation. One pathway would be to just continue with the existing market structure, which could soon lead to a situation where utilities lose revenue because their energy sales are going down. The other pathway is utilizing this transition and putting the right kind of mechanisms for revenue models in place. As a result, the reliability of the system is maintained or improved. There are a bunch of reasons to experiment with different ways in which the distributed resources can be part of the overall energy system.

Fuhs: Even if it's not all about infrastructure, technology and costs play a significant role. Many in our industry wonder whether there are other technologies to come soon and whether there will be a game changer. What do you envision?

Mayr: There are some interesting new technologies out there. But in the short- and mid-term we have a set of mature lithium-ion and flow battery technologies that compete in the market and will constitute the majority of installations. This is mainly because electrochemical systems are very complicated, and it takes a lot of time to bring a technology to the market and to scale it. And scaling is key to cost reduction. This said, there are a lot of interesting developments within the lithium-ion space. For example, there is the move to silicon-based anodes to increase the energy density or the move to solid state electrolytes with improved safety. Also very interesting is the shift to higher nickel content in NMC cells to increase energy density and to decrease the cobalt content, which might help to prevent potential bottlenecks in supply. Last but not least, the gradual improvement of separators to allow for thinner separators and higher energy density without compromising safety is a promising development.

Leuthold: On a regular basis we're asking ourselves this question. I don't know when solid state batteries will come. Generally with these technological developments I trust our colleagues from the automotive sector that they will drive this development. My personal favorite is the organic redox flow battery, where we have cheap materials. But this will take years. The decade to 2025 is the decade of lithium-ion. The interesting question will be what will be coming after the middle of the next decade.

Jansen: It is astonishing to see what manufacturers of lithium-ion are doing to change the composition of different lithium-ion chemistries to reduce costs. This is also why I don't believe that we're running out of resources to produce lithium-ion batteries. Very few people know what

"Implementing the energy transition goes beyond just installing renewable energy and infrastructure"

kind of new battery will come into the market, but we won't be running out of batteries any time soon. Also the long-term trend for cost reduction will continue, which can be linked to the continued growth in production capacity across the supply chain.

Fuhs: How about short-term price reductions in 2018?

Jansen: For smaller battery modules we recently saw a plateau in price reduction and even some reporting of small increases in pricing. In 2018, there will certainly be a slowdown in battery module price reduction, and potentially for smaller orders a very minor increase. But overall, we do not expect a huge sudden swing to batteries becoming expensive and making current stationary storage projects uneconomical.

Manghani: One thing that may make significant impact on cost reductions are second life batteries. In 2023 and 2024 when there will be a huge stock of used EV-batteries coming back into the market. That may have some implication for economics of stationary storage applications.

Fuhs: Many people wonder what will be the residual value of batteries in 10 or 20 years. What are your forecasts?

Leuthold: As battery costs fall, the residual value will fall just the same. The packs sold in cars today, when they get back to the market in 10 years they will not only have been used for 10–12 years, but will also be 10–12 years-old technology. They will then have to compete with new cell technology that has seen 10 years of development. On top of that you will have the cost of integrating used packs with differing states of health into one storage system. The question about a more exact value is very hard to answer. Also, recycling costs and value of recycled materials go into this consideration. It is hard to predict but we don't think it will be a massive value to reuse batteries. I prefer recycling materials and making new cells out of them.

"The decade to 2025 is the decade of lithium-ion"

Fuhs: What is the pure material cost of a battery?

Leuthold: Two to three years ago we considered $100/kWh the long-term limit for the material of lithium-ion-cells. Today we are discussing material prices of around $60/kWh and, depending on chemistry, as low as $25/kWh. That's purely material though; you know how it goes, cheaper materials tend to be more expensive in manufacturing.

Publisher information

Publisher
pv magazine group GmbH & Co. KG
Kurfürstendamm 64, 10707 Berlin, Germany

Editors pv magazine group
Ian Clover
Managing editor
Tel.: +49-30-213 00 50 38
clover@pv-magazine.com

Mark Hutchins
mark.hutchins@pv-magazine.com

Michael Fuhs
Editor in chief pv magazine Deutschland
fuhs@pv-magazine.com

Daniel Seeger
seeger@pv-magazine.com

Authors: Marija Djordjevic, Julian Jansen

Sales & Marketing Director
Andrea Jeremias
Tel.: +49-30-213 00 50 23
jeremias@pv-magazine.com

Sales
Fabienne Cuisinier
Tel.: +49-30-213 00 50 39
cuisinier@pv-magazine.com

Marketing Manager
Marina Ramain
Tel: +49-30-213 00 50 29
marina.ramain@pv-magazine.com

Production Manager
Cornelia Lichner
Tel: +49-30-213 00 50 18
cornelia.lichner@pv-magazine.com

Advertising Administration
Anika Wedemeyer
Tel.: +49-30-213 00 50 22
media@pv-magazine.com

Cover design
Stefan Lochmann

Layout and typesetting
Petra Plociennik

Layout design
Alexx Schultz

Printer
Sedai Druck GmbH & Co. KG, Böcklerstraße 13, 31789 Hameln/Wangelist

ISSN 1865-3138

pv magazine group

Visit us at
ENERGY STORAGE EUROPE 2018
13. – 15. March 2018
hall 8B
booth E22

ENERGY STORAGE
E3/DC

Maximum independence
in electricity, heat and mobility

ENERGY STORAGE E3/DC

E3/DC GmbH
Karlstraße 5 • D-49074 Osnabrück • www.e3dc.com • info@e3dc.com • (+49) 541 760268 0